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Helicopter terrain navigation training using a wide field of view desktop virtual environment

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THESIS

HELICOPTER TERRAIN NAVIGATION TRAINING USING A WIDE FIELD OF VIEW DESKTOP VIRTUAL ENVIRONMENT

by

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September 1998

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ABSTRACT ***(maximum 200 words)***

Helicopter terrain navigation is a unique task -- training for this task presents unique challenges. Current training methods rely on dated technology and inadequately prepare pilots for real-world missions. Improved training specifically tailored to address the unique needs of the helicopter community that capitalizes on recent improvements in desktop virtual environment (VE) technology could substantially improve the training process and reduce training costs.

Based on the input of subject matter experts in current helicopter terrain navigation training techniques and VE technology, such a system was developed and tested on student pilots performing real-world tasks. A desktop VE that presented a simple to control and learn, interactive fly-though of a terrain model was used to augment conventional training at Helicopter Antisubmarine Squadron Ten (HS-10).

Results indicate that flight time for students that received VE training was more productive than for students that received conventional training. This work justifies the next logical step; fielding a system on a long-term basis as a squadron asset. This system would provide improved training for the helicopter community and an invaluable source of research data for the Naval Postgraduate School.

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HELICOPTER TERRAIN NAVIGATION TRAINING USING A WIDE FIELD OF VIEW DESKTOP VIRTUAL ENVIRONMENT

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Submitted in partial fulfillment of the
requirements for the degree of

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September 1998

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Helicopter terrain navigation is a unique task -- training for this task presents unique challenges. Current training methods rely on dated technology and inadequately prepare pilots for real-world missions. Improved training specifically tailored to address the unique needs of the helicopter community that capitalizes on recent improvements in desktop virtual environment (VE) technology could substantially improve the training process and reduce training costs.

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I. INTRODUCTION

A. PROBLEM STATEMENT

Applications of emergent technology to training war-fighting skills should be firmly grounded on proven theory. The ideal discovery and application process for these theories mirrors Sir Julian Corbett's assessment of war-fighting strategy found in Naval Doctrine Publication 1 (Department of the Navy [DON], 1994, p. 35):

> *The last thing that an explorer arrives at is a complete map that will cover the whole ground he has traveled, but for those who come after him and would profit by and extend his knowledge, his map is the first thing with which they will begin. So it is with strategy... It is for this reason that in the study of war we must get our theory clear before we can venture in search of practical conclusions.*
>
> -- Sir Julian Corbett, 1911

The focus of this thesis is to use our current understanding of helicopter terrain navigation and virtual environment (VE) technology as the "map" provided by previous research. The goal is to extend this knowledge and draw practical conclusions related to the application of VE technology to terrain navigation training. Further, this work will test an implementation based on these conclusions and recommend areas for future exploration.

Helicopter overland navigation is a unique task. While it shares certain commonalties with conventional land and air (high altitude fixed-wing) navigation, it is, in fact, distinct in a number of ways. Training for this task presents unique challenges. Current training methods rely on dated technology, have not been validated, and are of questionable value. Although the application of VE technology to this problem has tremendous intuitive appeal, is this solution firmly grounded on proven theory? To date, VEs have not addressed issues specific to the needs of the helicopter community. Addressing these needs and validating the factors that define effective application of VE technology to helicopter overland navigation could substantially improve the current

training process, reduce training costs, and provide a uniquely rich source of research data on navigation knowledge, training methods, and human-computer interface issues.

B. ORGANIZATION OF THIS THESIS

This thesis is organized into the following chapters:

- Chapter I: Introduction. This chapter gives a general outline of the work, including an introduction to the problem, motivation, purpose, and outline.
- Chapter II: Background. This chapter contains pertinent background information, including a summary of navigational knowledge, a task description for helicopter overland navigation, a description of current training method, and a summary of VE and related works.
- Chapter III: Approach. This chapter describes the decision process followed to define the goals and features of the training apparatus. In general it answers the "what and why" decisions related to the system.
- Chapter IV: Implementation. This chapter describes how the system was implemented.
- Chapter V: Methods: This chapter describes experimental setup and execution. It provides necessary information to recreate the experiment.
- Chapter VI: Results: This chapter contains results of the experiment.
- Chapter VII: Conclusions: This chapter contains the conclusions reached through the testing process.

II. BACKGROUND

A. TRAINING THEORY

How do humans acquire and improve simple and complex skills that can be applied to a variety of specific situations? Clearly, design of a terrain navigation training system should be based on a thorough understanding of the principles of effective training. Although there is a wide variety of methods to learn and improve skills, these methods vary considerably in the degree to which they improve the skill, the rate at which they improve the skill, the degree of retention they promote, and finally, the cost. The sum of these criteria -- the greatest level of proficiency per dollar invested -- has been defined by Wickens (1992) as "training efficiency." The remainder of this section summarizes Wickens' comprehensive outline of training to provide background information relevant to the design of a helicopter terrain navigation training system.

1. Types of Knowledge

Wickens (1992) divides knowledge into two broad categories distinguished by the nature of the knowledge and the optimal form of training to increase performance. *Declarative knowledge* relates to facts that can be easily verbalized (such as the safety procedures for manufacturing equipment). Mastery of declarative knowledge can be achieved through study and rehearsal. *Procedural knowledge* relates to learning how to perform an action such as tying a shoe. Mastery of procedural knowledge is best accomplished through practice and performing. Helicopter terrain navigation would clearly seem to fit in the category of procedural knowledge. However, assuming that practice is the most efficient method of training may be premature. In fact, Wickens (1992) outlines seven other principles to enhance learning of either or both types of knowledge. These principles are outlined in the following section and provide useful guidelines for developing a training system.

2. Strategies to Improve Learning

a. Practice and Over-learning

Most people would agree that repetition is an effective learning technique. Few are likely to agree, however, on how much practice is appropriate for a given task. Is it appropriate to repeat the training until trainees achieve errorless performance? Does this guarantee errorless performance in practice? Probably not. Errorless performance fails to account for two other vital aspects of training: speed of performance, and the attention resource demand. Individuals whose training stops after they achieve errorless performance will not have the opportunity to improve other aspects of performance. Anderson (1981) demonstrated that speed of performance increases at a rate proportional to the logarithm of the number of practice trials. Related studies by Fisk, Ackerman, and Schneider (1987) and Schneider (1985) demonstrated that repeated practice (past the point of errorless performance) will reduce the attention or resource demands, and will eventually allow the skill to be performed in an automated fashion like touch-typing. From this, it is clear that an effective training system will not necessarily be focused on or limited to the simple goal of errorless performance.

b. Elaborative Rehearsal

Craik and Lockhart (1972) define two types of rehearsal: rote and elaborative. *Rote rehearsal* involves simple recycling of phonetic code. This type of rehearsal is useful for short-term applications: it is effective at maintaining information in working memory, but does little to affect long-term memory. On the other hand, *elaborative rehearsal* involves relating the meaning of material with other information already in long-term memory. This process is crucial for creation of long-term memory representations. Thus, a training system that incorporates elaborative rehearsal would be more likely to affect long-term memory than a training system that relied primarily on rote rehearsal.

c. *Reducing Concurrent Task Load*

Tasking student pilots with too much too soon can be detrimental to the learning process. Research has demonstrated that if the task is initially overwhelming, students may not have sufficient resources to perceive and understand task consistencies (Lintern & Wickens, 1987; Schneider & Detweiler, 1988). In general, it has been shown that if the workload of the environment is excessive, effective learning will not take place (Nissen & Bullemer, 1987; Schneider, 1985; Schneider & Detweiler, 1988; Sweller, Chandler, Tierney & Cooper, 1990). This concept strongly supports a method to break complex tasks into simpler functions that can be learned independently. This concept is discussed further in Section II.A.2.f.

d. *Error Prevention*

If repetition leads to learning, then clearly, allowing trainees to repeat incorrect actions would increase the chance of negative training. That is, if trainees are allowed to repeat incorrect actions during training, they may develop habit patterns that will result in poorer performance during task execution. The concept behind error prevention is basic: provide the trainee feedback that reduces the initial workload and thus allows them to ingrain the correct actions. While this training scheme has tremendous intuitive appeal, there is a hidden risk. Transfer from the training environment to the real environment is sometimes poor. When student pilots were provided with this type of augmented feedback in a trainer (a path indicating the correct approach to the runway) their subsequent performance in the aircraft was poor (Lintern & Roscoe, 1980; Winstein & Schmidt, 1989). It is apparent that users can become dependent on information presented during the training sessions. When this information is no longer available, students are unable to adapt to processing a different set of cues. A variation of the feedback mechanism, *off-target feedback*, compensates for this by providing cues only when some deviation criterion has been met. Feedback is provided only when some performance threshold has been exceeded. Off-target feedback has been proven effective in training aircraft landing skills (Lintern, 1980; Thomley-Yates, Nelson & Roscoe, 1987). Training systems must achieve a careful balance; too little feedback

creates the opportunity to reinforce negative habits, too much feedback creates dependencies that may result in worse whole task performance.

e. Adaptive Training

Adaptive training is a useful mechanism when the complete task may initially overwhelm the trainee and some component of the whole task can be simplified. As training progresses, the difficulty of this component task is raised until the entire target task is being trained. Efforts to prove the efficacy of adaptive training reveal little advantage to this technique when compared to conventional training methods (Lintern & Gopher, 1978; Lintern & Wickens, 1987). Although the factors that control the effectiveness of this training have not been defined clearly, the lack of demonstrated improvement could be from several causes. The simplification may not release sufficient resources to aid learning the remainder of the task, or the initial version of training may actually induce incorrect expectations and responses. Trainees may not be provided ample opportunity to develop time-sharing strategies required for success in the complete task.

f. Part-task Training

Part-task training involves breaking a complex task into individual elements that can be trained separately. Figure 1 depicts two distinct forms of part-task training as defined by Wightman and Lintern (1985). Segmentation training applies to situations in which the whole task can easily be divided into sequential phases. The more difficult phases can be repeated an arbitrary number of times prior to training other phases or the whole task. Wightman and Lintern (1985) demonstrated that segmentation part-task training produces better whole task performance when compared to other forms of training. Fractionization involves practice on items that must be performed concurrently in the whole task. Practicing the mechanical act of shifting gears without driving is an example of fractionization part-task training. The benefits of fractionization part-task training are not as clear as segmentation training. Separating tasks into components may prevent the development of crucial time sharing skills required for success in the whole task (Lintern & Wickens, 1987; Wickens, 1989). The results of

these works suggest that part-task training is effective if it is applied to components that can be separated from the whole task and can be automated.

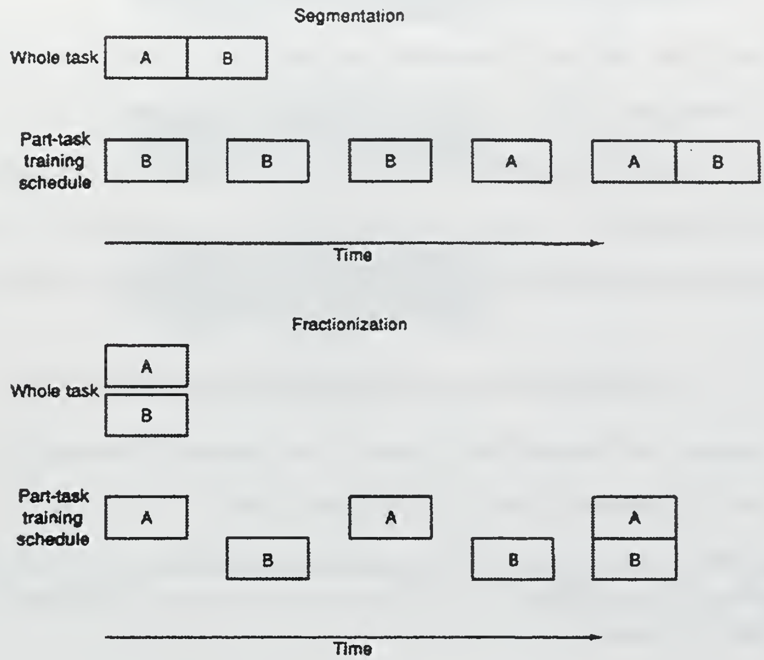

Figure 1. From (Wickens, 1992). Segmentation and fractionization part-task training.

g. Knowledge of Results (KR)

The benefits associated with providing feedback about the quality of performance, or knowledge of results (KR), are clear: it is useful for motivation as well as for correcting and improving performance (Holding, 1987). The optimal quantity and method for delivery of KR is not as clearly defined. Two extremes bracket the ideal timing of KR. If KR is offered while the skill is being trained, the learner may not have adequate attention to devote to both information sources; one task will suffer. In one study, verbal cues provided to student pilots learning to land were actually found to interfere with the learning process (Lintern & Wickens, 1987). On the other hand, if KR is delayed too long and the interval is filled with other activities, the feedback may not be effective. Determining and adjusting the KR feedback is clearly one of the more vital roles in the training system design process.

B. NAVIGATION THEORY

1. A Model of Navigational Knowledge

In keeping with the goal described in Chapter I, clearly any application of VE technology to helicopter terrain navigation should be based on the most complete understanding of navigation knowledge. Although navigation is a vital task in daily life, there is no clear consensus on how humans learn to navigate. This section briefly summarizes several key works to provide a basic framework of navigational knowledge.

a. Hierarchical Levels of Navigational Knowledge

Based on Thorndyke's model, navigational knowledge is divided into three distinct level defined as follows (Thorndyke, 1980):

- Landmark knowledge: The ability to recognize and distinguish critical features of an area.

- Route knowledge: The ability to repeat paths from one known location to another known location.

- Survey knowledge: A more complete level of understanding of a space, characterized by the ability to infer paths between known locations within the space.

These levels are hierarchical in nature. Knowledge at successive levels requires some degree of mastery at previous levels. These levels are depicted in Figure 2. The following section describes current understanding of how each level of knowledge is acquired.

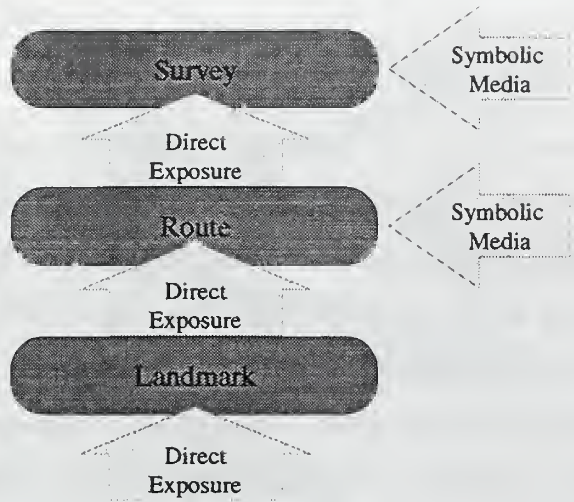

Figure 2. Levels and acquisition of navigational knowledge.

b. Navigational Knowledge Acquisition

Figure 2 depicts methods to acquire navigation knowledge. Landmark knowledge and route knowledge are acquired by direct exposure to the environment (Goldin & Thorndyke, 1982). Exposure to the environment can take place in the actual environment or a representation of it. Several works have demonstrated that a variety of media can be used to represent an environment. In each case, direct exposure to media other than the actual environment resulted in lower levels of general navigational knowledge than exposure to the actual environment (Thorndyke & Hayes-Roth, 1978; Thorndyke, 1980; Anderson, 1979).

Survey level knowledge is believed to be acquired in one of two ways: through repeated direct exposure to the environment or through map study. Although Thorndyke (1980) demonstrated that repeated direct exposure to an environment can lead to survey level knowledge, it is not clear if this is always the case. Chase (1983) demonstrated that individuals who received extensive repeated direct exposure to environments but were never exposed to maps did not necessarily develop spatial knowledge.

2. Other Cognitive Aspects of Navigation

a. Contour Map Interpretation

Contour maps use an abstract concept to represent three-dimensional objects (terrain relief) on a two-dimension medium (paper map). These maps use lines connecting points of equal elevation, or contour lines. The distance between the lines generally indicate the degree of slope (lines close together indicate steep slopes, lines spaced far apart indicate gentle slopes.) The shape of terrain features must be inferred from the curvature of the contour lines. An example of a contour map and the terrain it represents is shown in Figure 3. Terrain navigation, therefore, involves matching the viewed scene to a contour map. The user must associate visible terrain features to map representations. It is generally acknowledged that this is the most difficult form of map interpretation (Simutis & Barsam, 1983). Contour maps are produced by the Defense Mapping Agency (DMA) to accommodate a variety of users. One of the most important characteristics of maps is the scale used. Dismounted infantry usually rely on 1:24,000 meter scale maps. Helicopter crews use both 1:250,000 and 1:50,000 maps, while fixed wing aircraft generally use 1:250,000 scale maps.

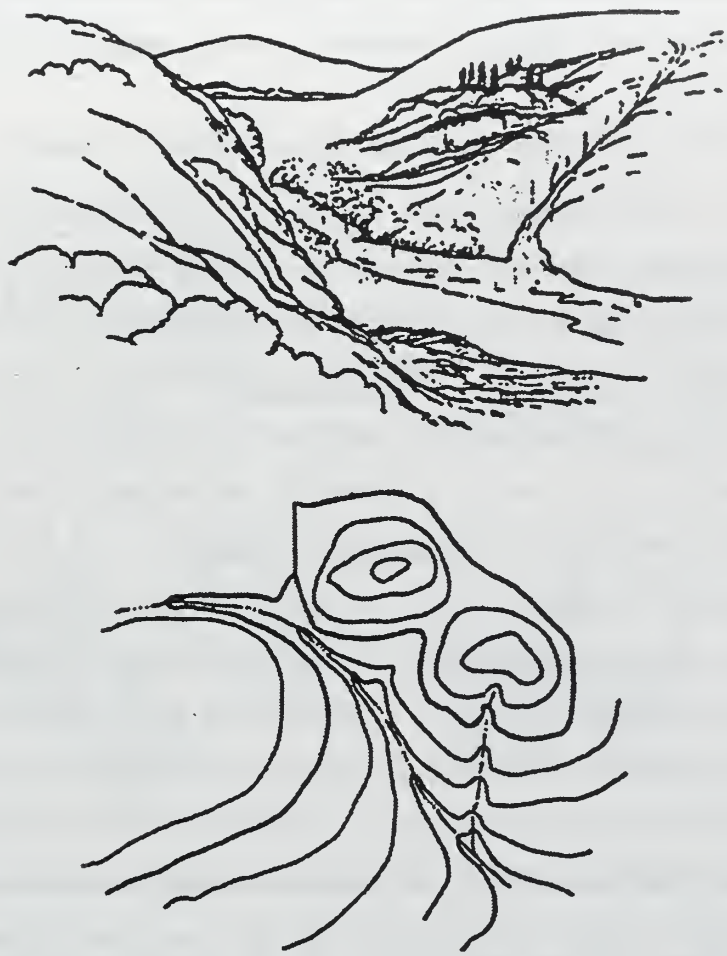

Figure 3. From (Simutis & Barsam, 1983). Contour map representation of terrain features.

b. Map Rotation

Almost everyone uses, and thus is exposed to the basic principles of map usage. One of the most fundamental issues related to map usage is the direction of orientation of the map. Is it more appropriate to turn the map to align it with the user's direction, or are fixed, north-up maps easier to use? The answer to this question may depend on both the task and the user's preference. Generally, for tasks that are egocentric in nature (such as following a route), maps oriented in the direction of travel minimize the cost of mental rotation and have been demonstrated to be more effective (Aretz, 1991; Harwood & Wickens, 1991). This cost of mental rotation is depicted in

Figure 4. However, if the task involves planning and communicating with individuals who do not share the same frame of reference, north-up maps may be more appropriate (Wickens, 1992).

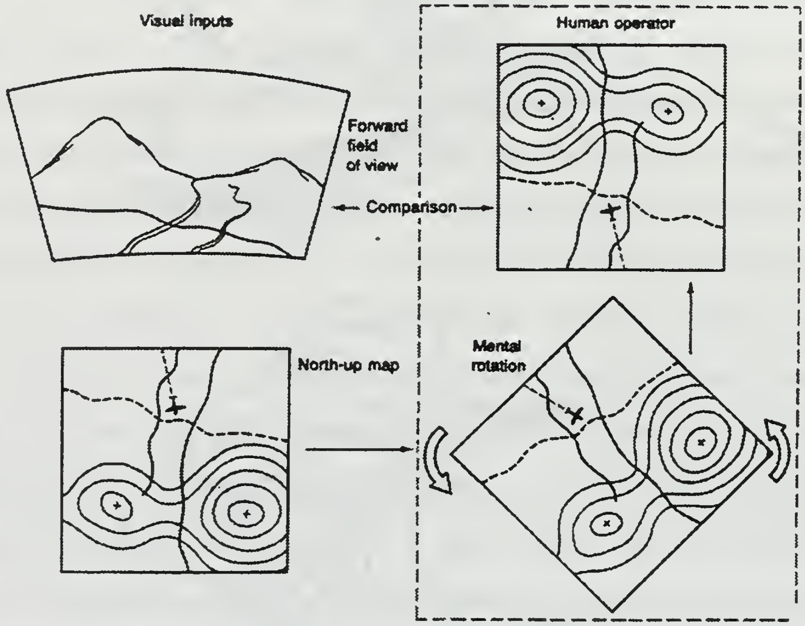

Figure 4. From (Wickens, 1992). Map alignment and the cost of mental rotation.

Cevik (1998) studied the issue of map orientation in VEs for a variety of ego and exocentric tasks. His findings support the generalizations described above. Further, he found that individuals with high spatial ability (ability to perform mental rotations) were able to use forward-up maps to perform a variety of egocentric world reference frame tasks. Since it can be assumed that pilots have high spatial ability (high performance on spatial ability tests is a prerequisite for flight training), this work suggests that even for tasks in the world-reference tasks, forward-up map displays are preferable to north up maps for this user group.

C. LESSONS FROM RELATED VIRTUAL ENVIRONMENT APPLICATIONS

1. Transfer of Spatial Knowledge Acquired in Virtual Environments

Several works have demonstrated that a variety of VE systems and interfaces can be effective tools to promote navigational knowledge of a real-world environment. Bliss, Tidwell, and Guest (1997) demonstrated that spatial knowledge acquired in a VE can be transferred to real-world structured environments. They studied 30 firefighters using a virtual model of an office building. Firefighters who used the VE performed better than a group that studied blueprints of the building. Based on improved navigational performance, Bliss et al. (1997) assert that VEs are effective media to promote navigational knowledge of an area. While this is encouraging, is it correct to assume that navigation in structured environments (such as the building used by Bliss et al.) is the same as navigation in natural environments? Darken and Banker (1997) studied this issue. They found that subjects exposed to a virtual model of a natural environment also demonstrated improved navigation ability. Goerger (1998) expanded on this work using a high-fidelity, real time, wide field of view VE. However, his work demonstrated that for short exposure times, study of high quality maps leads to better performance compared to VE exposure.

While it is encouraging that knowledge gained in VEs (for both structured and natural environments), results in improved performance on real-world navigation tasks, these works relate to environment-specific, mission rehearsal tasks. They do not address the use of VEs for generalized, environment non-specific training. Additionally, these works do not establish if they can be used to promote improved performance for *existing* real-world tasks.

2. Active Control Versus Passive Viewing

Williams, Hutchinson, and Wickens (1996) also studied the issue of navigation knowledge acquired in VEs. They compared subjects who actively controlled a fly-through of a terrain model with subjects who passively viewed the fly-through. Not surprisingly, the group that exercised active control performed better than the group that

participated passively. From this, it is reasonable to assume that interactive control of a fly-through is preferable to passively viewing a scene for navigational knowledge acquisition.

3. Performance Degradation Due to Interface

Witmer, Bailey, and Knerr (1995) conducted a study of 64 college students using various media to learn to navigate in a large office building. A group that received VE exposure was compared to groups that received verbal directions or exposure to the real environment. While the VE group performed better than the verbal direction group, the interface to the VE may have negatively impacted subjects' experience. Several subjects spent a significant amount of time disoriented in the VE. The VE involved an immersive BOOM display. When users collided with walls, it was very difficult for them to back up and negotiate the troublesome area. Goerger (1998) also concluded that interface issues were responsible for degradation of users' VE experience. Clearly, if a VE was created as a training system, it must involve an interface that minimizes the opportunity for users to become disoriented.

D. HELICOPTER TERRAIN NAVIGATION

Helicopter terrain navigation is a uniquely challenging task. The capabilities and missions of helicopters put them in environments where navigation is extremely difficult. The difficulty associated with helicopter navigation is well documented (Hackworth & Sherman, 1989, p. 657):

> *It was dark by the time I coordinated air assets with Brigade and headed by chopper toward the contact area. .... all I had to go on to find the contact area in the pitch-black night were the grid coordinates. I studied my map under a red light in the chopper, cursing the Delta, which looked the same wherever you went, and myself for never having mastered map reading at two and a half miles per hour let alone at a hundred mph. Then I looked out the door, and there, suddenly, right below me was an exact replica of the objective area I was looking at on my map -- just the right crisscross of canals, the same curve in the Mekong River.*

Why do helicopter crews often rely on luck? This section provides background information on the task of helicopter navigation and describes what makes it such a

difficult and unique task. This information will be helpful in discussing training techniques, the potential application of VE technology, and highlights specific requirements of training devices designed for the helicopter community.

1. Basic Helicopter Terrain Navigation Task Description

Why is it so hard for helicopter crews to find their overland targets? The Assault Support Helicopter Manual describes the fundamental skill required and lends some insight (CNO, 1992, p. 13-3):

> *The copilot/observer ... must be able to visualize from the map how the terrain around him should appear. He must also be able to look at the terrain, identify his location, and locate his position on the map.*

Looking at the terrain and correctly identifying a position on a map is not a trivial task. Helicopter crews generally use DMA 1:50,000 meter contour maps that, as outlined in Section II.B.2, use a distant abstraction to represent landforms. The level of abstraction varies with altitude and is most extreme at ground level. This concept is familiar to infantrymen. From their perspective, terrain navigation involves analyzing contour maps to create a mental picture of the shape of depicted landforms. They then compare these mental models with the egocentric view to decide if there is any correlation. The process of associating viewed terrain features and the contour map continues until a match is found. Since helicopters are capable of, and routinely exploit, flight regimes near ground level, the task of terrain association is similarly difficult. However, considering that troops move at about five miles per hour and helicopters move at about 120 miles per hour, helicopter crews have much less time to form this mental picture and make comparisons. Although helicopter terrain navigation involves the same basic skills as traditional land-based terrain navigation, it is considerably more difficult.

This notion is depicted graphically in Figure 5 and Figure 6. Figure 5 represents a top-down view of two helicopters; one with a 30-degree field of view, the other with a 90-degree field of view flying from left to right. The shaded box along the helicopter's flight path depicts the time each helicopter will have the terrain feature in view. Both aircraft visually acquire the feature at time T_0. The aircraft with the 30-degree field of view loses sight of the feature at time T_1. The aircraft with the 90-degree field of view

maintains sight of the feature until time T_2. Figure 6 plots the time that a feature will be in view based on how far the feature is from the helicopter's track. These plots are based on a feature that is visible from 4 nautical miles (NM) viewed by a helicopter traveling 90 nautical miles per hour (kts). For a feature that is .5 NM from the intended track, a 30-degree field of view provides 1.4 minutes to view the feature, while a 90-degree field of view provides 2.3 minutes. Considering the number of features to view and correlate to map representations, this is precious time.

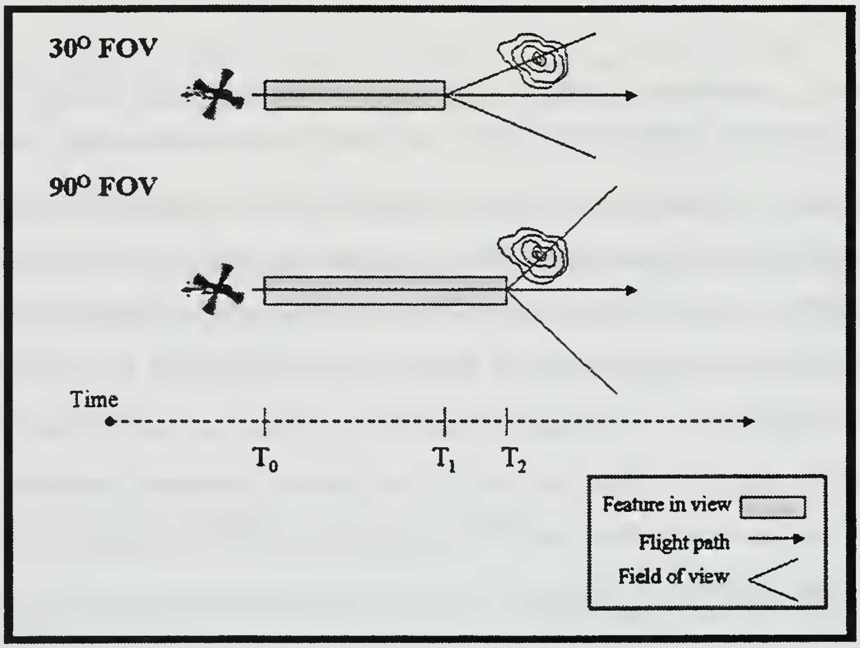

Figure 5. Time available to view a terrain feature based on field of view.

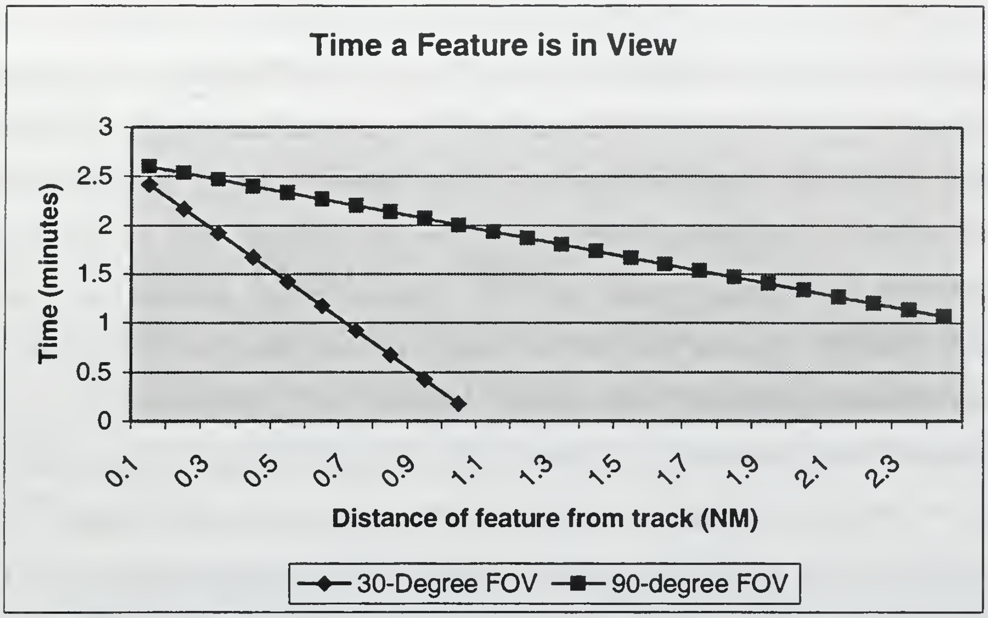

Figure 6. Time to view a feature as a function of distance of feature from track for a helicopter flying 90 kts.

Do fixed wing aircraft share this dilemma? Fixed wing aircraft are constrained by maneuver limitations to regimes where maps closely represent cockpit views. Because of the high speed and large areas involved, fixed wing aircraft generally use 1:250,000 meter air navigation charts. At normal fixed wing operating altitudes, these maps closely resemble cockpit views. Rivers are clearly visible from high altitudes and their curves and wanderings can easily be compared to map representations. Likewise, major landforms such as mountain ranges and ridgelines look similar to map representations. Although fixed wing aircraft move considerably faster, there is less mental transformation from the map to the scenery.

a. Flight Planning

One of the initial steps in helicopter overland navigation is map study. The purpose of map study is to gain familiarity with the general terrain, vegetation, hydrographic, and cultural (man-made) features of the area. Map study includes a detailed review of hazards. These are generally associated with man-made features and include power lines, towers, and supporting guy wires, and cable car and logging lines. After crews are familiar with the general features of the area, they evaluate possible

routes to the objective area. Routes are defined by a sequence of checkpoints. Generally, the path between the checkpoints is only roughly planned. Routes are planned with specific criteria based on the mission; however, several factors are consistent for all missions. Route planning should make the best possible use of the terrain. Since the primary means of navigation relies on terrain recognition, one of the fundamental considerations is choosing routes that will connect terrain features that are easy to recognize. Terrain features used to aid navigation fall into three categories: checking features, channeling features, and limiting features. A *checking feature* is any easily distinguished terrain feature that will be visible along the route. Any unique landform that can be seen from the planned altitude can be used as a checking feature. Examples include distinct river bends, stream intersections, and uniquely shaped peaks. Checking features are often used as checkpoints. *Limiting features* are easily identified landmarks that indicate a checkpoint has been missed. A prominent river that is perpendicular to and beyond the planned flight path could be used as a limiting feature. *Channeling features* are used to maintain orientation during the transit between checkpoints. Following a river or ridgeline is an effective use of a channeling feature. When planning helicopter routes, crews generally avoid relying on man-made features for navigation. Man-made features are generally near population centers. In wartime, enemy forces will protect these areas. Additionally, man-made features may be gone (battle damage) or decoys may be used. Careful route selection and judicious use of checking, channeling, and limiting features simplifies navigation.

b. In-flight Roles and Procedures

The introductory paragraph to this section describes the basic procedure to navigate in the terrain flight environment; maintain orientation by comparing terrain features to the contour map. This is normally the task of the non-flying pilot. He or she maintains orientation on the map and directs the flying pilot with precise verbal commands. To simplify communication, these commands use only standardized terminology. This terminology should allow the flying pilot to complete all actions without reference to cockpit displays. For example, it is effective to direct the flying pilot with the commands "Turn left" and "Stop turn". It is ineffective to direct the pilot

to "Turn to zero nine zero". This command would require the pilot to reference the compass prior to initiating the turn. The non-flying pilot may also rely on other crewmembers to identify landmarks and features out of his or her field of view. Again, standard terminology reduces communication bandwidth and the potential for confusion.

2. Helicopter Flight Profiles Defined

Flights conducted below 200' AGL where navigation is performed by visual reference to terrain features and landmarks fall into the broad category of *terrain flight*. Terrain flight is further divided based on the altitude and airspeeds used as follows (CNO, 1992, p. 13-5):

- **Low Level Flight**: Flight conducted at a selected altitude at which detection and observation of the aircraft or of the points from which, or to which, it is flying are avoided or minimized. The flight route is preselected, generally a straight line and is flown at a constant airspeed and indicated altitude. See Figure 7.

- **Contour Flight**: Low altitude that conforms generally and in proximity to the contours of the Earth's surface. It takes advantage of available cover and concealment to avoid an enemy's observation or detection of the aircraft or its departure and landing. It is characterized by the varying of airspeed and altitude as vegetation and obstacles dictate. See Figure 8.

- **Nap of the Earth (NOE)**: flight as close to the Earth's surface as vegetation and obstacles permit while generally following the contours of the Earth's surface. Altitudes and airspeeds are selected based on weather, lighting conditions and enemy situation. The pilot preplans a broad corridor of operation based on known terrain features with a longitudinal axis pointing towards his objective, but in flying it he uses a weaving and devious route within the corridor an oriented along the axis to take advantage of the cover and concealment afforded by terrain, vegetation, and man-made features. See Figure 9.

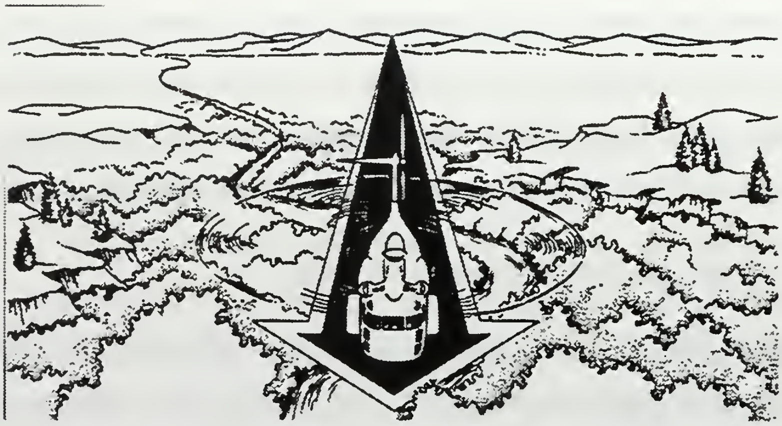

Figure 7. From (CNO, 1992). Low level flight profile.

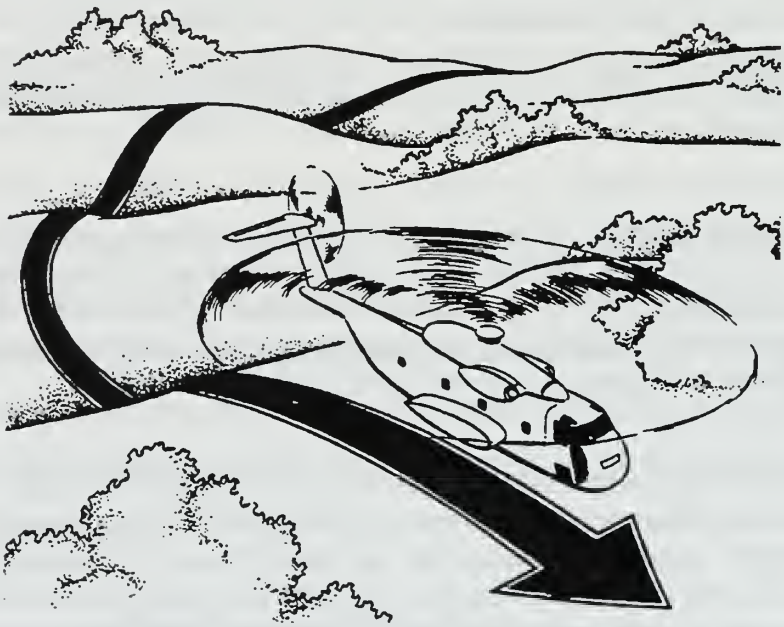

Figure 8. From (CNO, 1992). Contour flight profile.

Figure 9. From (CNO, 1992). Nap-of-the-earth (NOE) flight profile.

3. Selection of Terrain Flight Profile and the Effect on Workload

Helicopter flight profiles are selected to optimize tactical employment of the aircraft and the terrain. The profile flown is selected with the goal of "...employment of an aircraft in such a manner as to utilize terrain, vegetation, and man-made objects to enhance survival by degrading the enemy's ability to visually, optically, and electronically detect or locate the aircraft," (CNO, 1992, p. 13-2). This concept is generally referred to as *terrain masking*. The primary consideration is to remain hidden by terrain to minimize exposure to threats. Helicopter crews limit the chance for visual detection by flying in draws and canyons, and using vegetation. Unfortunately, limiting the ability of the enemy to see the aircraft makes it harder for the crew to navigate. Both the navigation task and general workload associated with flying increase significantly as altitude decreases.

a. Navigation Task

A primary reason the navigation task changes with altitude stems from the fact that the degree to which terrain features resemble their contour map representations changes with altitude. It is more difficult to navigate at lower altitudes because map representations are a further abstraction from terrain features. As summarized in (CNO, 1992, p. 13-3).

> *Low level flight navigation is easiest because, at the higher altitudes, the copilot/observer can more accurately identify shapes which are depicted on the map. He has the greatest difficulty during NOE flight, because navigation is primarily by vertical relief, which he must interpret from the map.*

This is not the only factor that makes navigating at lower altitudes more difficult. At high altitudes, there are relatively many distinguishable features. These features will remain in view for much longer than the features in view at NOE altitudes. Thus, when navigating at low level altitudes, pilots can rely on relatively few distinguishable landmarks between checkpoints. As heading between checkpoints is held relatively constant and groundspeed is constant, dead reckoning techniques are much more effective. At NOE altitudes, the number of easily distinguished features is substantially reduced. There is much less time available to compare terrain features to possible map representations. The serpentine nature and varying speeds of NOE routes make dead reckoning techniques ineffective. The relative number of features pilots need to correctly identify along an NOE route is significantly higher than along the same route flown at contour or low level altitudes.

b. Flying Task

The level of difficulty of flying also varies greatly over the range of altitudes. At low level altitudes, there is a comparatively long time to analyze emergencies and malfunctions. Obstacles are scarce, generally well marked on maps, and clearly visible from the air. The flying pilot can easily ensure obstacle clearance without assistance from the crew. At contour flight profiles, the workload increases significantly. The number of potential hazards increases, and the reaction time available

decreases. Crews are more likely to encounter uncharted hazards such as power lines. Increased vigilance is required; the flying pilot may require assistance from crewmembers to ensure obstacle clearance.

The workload associated with NOE flight is considerably higher. Nap-of-the-Earth flight requires higher power settings than other profiles. These power requirements limit the time and flexibility helicopter crews have to respond to emergencies. Thus NOE flight paths demand careful planning, forethought, and attention. For single rotor aircraft at NOE speeds, the slipstream that normally helps control the tail is no longer present. Because of the reduced obstacle clearance, tail rotor control is more critical. To make the best use of available cover and concealment, crews must operate with minimal obstacle clearance. In these profiles, the flying pilot must rely on information from the other crewmembers to ensure obstacle clearance. This significantly increases the amount of communication between crewmembers. Figure 10 depicts an example of why the flying task is more difficult. For conventional (not terrain) flight, pilots use the center of mass as the rotation point. In the terrain flight environment, this would be extremely hazardous. From Figure 10, it is readily apparent that pilots must fly using a different rotation point. Since the flying pilot cannot see the tail of the aircraft, he or she must rely on peripheral vision and advice from crewmembers to avoid colliding with terrain or vegetation. This one maneuver is a typical example of the increased workload associated with flight in the NOE environment.

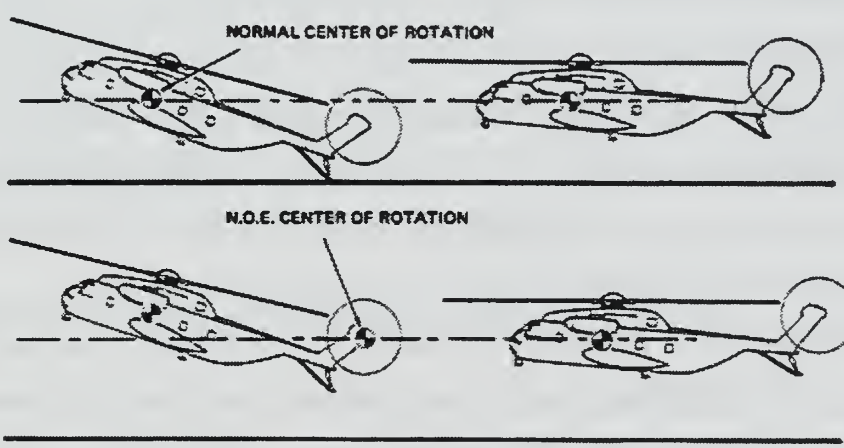

Figure 10. From (CNO, 1992). Terrain flight "quick stop" maneuver.

4. Navigating in Combat Search and Rescue Scenarios

Navigation is never the end goal -- it is always a subsidiary and prerequisite component of a larger task. One such task, Combat Search and Rescue (CSAR), incorporates navigating in the regimes described in the previous section. The nature of CSAR missions further complicates the role of navigation for helicopter crews. A more complete description of CSAR missions can be found in Doctrine for Joint Combat Search and Rescue (Joint Chiefs of Staff [JCS], 1996) and (CNO, 1992). This section summarizes these publications to provide amplifying background information related to helicopter navigation in the CSAR environment.

The mission of CSAR is recovery of personnel in hostile areas. This broad definition covers a wide variety of aircraft in a wide variety of threat environments. The preferred method of recovery is the single unit recovery. This method uses a single helicopter or a flight of helicopters to penetrate hostile territory and recover personnel. Defense is accomplished by remaining undetected through use of terrain masking, darkness, or adverse weather. If conditions are not favorable for a single unit recovery, a CSAR Task Force (CSARTF) will be used. Employing a CSARTF requires considerably more coordination and complicates the task for the rescue helicopter. Additional aircraft involved in the effort may include Rescue Escort (RESCORT), Rescue Combat Air Patrol (RESCAP), and an Airborne Mission Commander (AMC.) The primary role of the RESCORT is to provide protection for the rescue helicopter from surface threats. The RESCAP's primary role is to provide counter-air and electronic warfare support to the CSARTF against airborne and surface threats. If needed, an AMC may be assigned, primarily to provide coordination. Coordination tasks include managing the flow of aircraft to and from the objective area, arranging aerial refueling, and coordinating no-fire zones in the objective area. For each stage involved in the CSAR mission, the navigation task for helicopter crews is more difficult when a CSARTF is used.

The unique route planning requirements for a CSARTF complicate the task of navigation. Because enemy forces are unpredictable, routes must be planned to ensure success if hostile forces appear in unexpected places. Additionally, distinct ingress and egress routes are planned to minimize the enemy's opportunity to prepare attacks on outbound aircraft. Further, support aircraft (in particular, the RESCORT) are only

effective if they can readily locate the rescue helicopter, so they must maintain a fix on the helicopter. They cannot maintain this fix by assuming a fixed relative orientation to the helicopter, as this tends to beacon the helicopter's position. Therefore, routes must be planned that allow for separate ingress and egress routes, the ability to change routes if needed, and the ability to broadcast these changes to support aircraft. There must also be provisions for support aircraft to locate the helicopter quickly without beaconning the helicopter's position.

One scheme to accomplish these goals is the use of *spider routes*. A series of checkpoints is selected based on the criteria described in Section II.D.1. These checkpoints are assigned code names. Crews designate primary and alternate ingress and egress routes by connecting checkpoints. The helicopter crew can covertly provide position information to support aircraft by reporting their position in reference to the named checkpoints. If necessary, the route can easily be altered by broadcasting a new sequence of checkpoints. This scheme provides the flexibility needed to successfully navigate to downed aircrew in hostile locations.

Incorporating spider routes significantly increases the workload and changes the type of navigation knowledge needed. It is generally not feasible to rehearse each permutation of the checkpoints. Since flight profiles are selected based on the tactical situation, it is unlikely that crews will be able to accurately predict where along the route they will be at NOE altitudes and where they will be at contour level altitudes. As outlined in Section II.D.3, flight at these different profiles are different tasks, and consequently if rehearsed, should be rehearsed as distinct tasks. Additionally, pilots must be prepared for more than only a primary ingress and egress route. They must be prepared to adapt the route as the tactical situation progresses. It is not always practical or productive to study the routes between each checkpoint.

E. LIMITATIONS OF CURRENT TRAINING METHODS

Based on the critical nature of navigation in missions such as CSAR described in the previous section, navigation training should receive high priority. However, training for improved navigation skills is an extremely difficult task and current training methods

have not fully overcome these difficulties. This section outlines some of the limitations of current training methods.

It is important to note that the navigation task changes based on the terrain flight profile selected (terrain flight profiles are described in Section II.D). Training for one profile does not necessarily improve a pilot's ability at other profiles. Terrain interpretation skill and other factors are unique enough in each regime that they cannot be trained simultaneously. This concept is summarized in (CNO, 1992, p. 13-6).

> *Navigation during terrain flight would be no appreciable problem for the experienced pilot if the navigational skills used at higher altitudes could be employed at terrain flight altitudes. However, these skills cannot be transferred and experience navigating at altitude does not prepare a pilot for navigating in terrain flight, particularly when using NOE flight techniques.*

The factors common to each terrain flight profile are discussed further in the following sections.

1. Difficulties Associated With Training Flights

The difficulties of terrain navigation training are not limited to the high cost and limited amount of flight hours available. Even with unlimited financial resources, effective airborne terrain navigation training is extremely difficult. Although terrain association is a fundamental skill required for overland missions, terrain flights may not be the best method to improve this component of the overall task. Training this skill may be easier and more effective using some ground-based media. This could not only improve terrain navigation training, it could allow instructor pilots (IPs) to devote more flight time to the aspects of CSAR that can only be learned in the aircraft.

a. Limited Resources

Every resource that is required for effective in-flight navigation training is limited. One such resource is a suitable training area. The features of the ideal training area are summarized in Table 1 and described in further detail in this section. These requirements are extremely restrictive and can only be met to a limited degree in the real world. The nature of navigational knowledge acquisition (discussed in Section II.B)

further restricts the usefulness of training routes. Thus, suitable terrain navigation routes are a scarce resource and precious commodity.

Features of Ideal Terrain Navigation Training Area
Close to training bases
Provide wide variety of terrain and vegetation
Provide climactic changes
Unpopulated
Support simultaneous use by multiple aircraft
Hazard free
Have few man-made features
Support routes with varying levels of difficulty

Table 1. Features of ideal terrain navigation training area.

To be cost effective, training routes must be close to training bases. It is not financially feasible to support long transits or detachments to alternate training areas. Because of the low altitudes involved, navigating over populated areas is both unsafe and unpopular. Consequently, routes must be in unpopulated areas. Since training emphasizes reliance on terrain rather than man-made features, the area should have few man-made features. If students could fly the routes by referencing man-made structures, they would not need, and therefore may not develop, terrain association skills. Further, man-made features often create flight hazards. Power lines, guy wire supporting towers, and cable car lines present hazards to flight crews. Not only could these be used as landmarks, they pose a significant threat. Ideally, training routes should incorporate a wide variety of the distinct features crews use as checkpoints, limiting features, and channeling features as described in Section II.C.1. In the ideal environment, routes could be designed with varying levels of difficulty. Repeating routes could lead to overconfidence and overestimation of a crew's ability to perform missions when their only preparation tool is a map. In the ideal training environment, crews could fly over various types of terrain, vegetation, and climatic environments. Simultaneous support for

use by multiple aircraft is problematic. If students plan their own routes, and are allowed to stray from these routes, the chance of a midair collision increases significantly.

Not only are navigation routes rare, the nature of spatial knowledge acquisition limits the degree to which routes can be reused. Each time a route is repeated, landmark knowledge increases. The second time a student traverses a route, they may remember the correct path based on features they recognize. If students can recognize where they need to fly based on landmark knowledge, they no longer need to rely on terrain interpretation skills. When training terrain interpretation, routes may only be effective the first time they are used.

As outlined in Section II.D, crews are not training to navigate for the sake of learning their way around the countryside. They are learning how to transit hostile areas to perform vital missions. Combat Search and Rescue is a difficult mission with many separate component tasks. On CSAR training flights, IPs must devote time to each of these component tasks. This requires careful time management. Many of the other skills required in CSAR missions could not possibly be learned in alternative environments. The quick stop maneuver described in Section II.D is only one of eight specific flight maneuvers students practice on terrain flights. As with quick stops, each of these maneuvers require high degree of situational awareness, crew coordination, and peripheral view. Obviously, these factors cannot be recreated in a synthetic environment, therefore, the aircraft is the only reasonable training medium. The number of new skills introduced to students during terrain flights affords IPs little leeway to devote extra time to any *one* of these skills. Any time spent circling a checkpoint to build terrain navigation skills takes away from time available to learn the many other components of CSAR.

b. Providing Effective Feedback

Are helicopter terrain flights the best method to learn how to associate terrain features and contour maps? Quality training depends on effective feedback. The nature of helicopter terrain navigation flight does not readily lend itself to a scheme that allows timely, effective feedback. It is extremely difficult for IPs to provide effective feedback on student's navigation performance while in the air. On terrain flight events,

the students act as the non-flying pilot and are responsible for navigation. The student's primary function is to maintain orientation on the map and provide directions for the flying pilot. If the student misidentifies a checkpoint, the IP must first determine which feature on the map the student confused with the correct one. The simplest way to do this would be for the student to indicate on a map the location of the feature. In the terrain flight environment, it is not always practical for the flying pilot to divert the attention this requires. Since the IP is the flying pilot, it is not practical for him or her to look inside the cockpit to check the student's map. Crews normally rely on a time-consuming verbal exchange. The student describes the feature on the map they believe corresponds to the landmark feature. Once the confusing features have been correctly identified, the ideal training environment would allow the student to repeat the difficult area. During terrain flights, this is logistically difficult. Maneuvering back to the same position and orientation is time-consuming, difficult, and potentially disorienting. Thus, both determining the source of student's errors and providing ample opportunity to learn from the error are extremely difficult in the aircraft.

Effective feedback must be tailored to the individual. The goal of a training command is uniform minimum level of performance. There is a wide variance in both the initial level of skill and the rate at which students improve (Simutis & Barsam, 1983). Instructors interviewed for this thesis noted that it is difficult to assess both the student's initial level of ability, and the rate at which they learn (Helicopter Antisubmarine Squadron Ten [HS-10], personal communication, May 30, 1998). This factor makes it difficult to provide precisely tailored feedback based on individual learning techniques and initial ability.

2. Limitations of Ground-Based Training

Based on the high cost and difficulties associated with training flights, training skills which can be improved on the ground could improve the training process and reduce costs. Current ground training aids rely on dated technology and have serious limitations. The media used and limitations are discussed in this section.

a. Three-dimensional Models

Scale relief models with contour maps overlaid are used to introduce the basic concepts of contour map interpretation. When viewed from directly above looking straight down, the model looks like a conventional contour map. If the model is viewed at an angle, the relief is visible. Thus, by transitioning from the overhead view to an angled view, the student can gain an appreciation for this abstract representation of terrain. These models have a number of strengths. One of the primary strengths is that it is effective for demonstrating how relief lines are used to represent terrain. Compared to orientation flights, they are cheap to produce and use. Models can be produced for a variety of types of terrain and are very effective at recreating a variety of vantage points. One of the basic limitations of three-dimensional models, however, is that they do not allow transition to an egocentric view. Although a wide range of views are available, three-dimensional models do not allow user's to recreate the egocentric view. This is a serious shortcoming as it is obviously the only representation available in the aircraft.

b. Video Home System (VHS) Based Map Interpretation and Terrain Association Course (MITAC)

The Map Interpretation and Terrain Association Course is divided into two major sections. The first section is a thorough tutorial on how to interpret contour maps. This section is divided into two parts. The first part is a detailed tutorial describing how contour maps are used to represent different terrain features. This part also includes definitions for terrain feature standardized terminology. Created and actual terrain features are shown from various vantage-points. These features are compared with their contour map representations. The second part of the first segment includes detailed coverage of all other map symbols. This includes basic hydrographic, vegetation, and cultural features.

The second part is a series of practical exercises in terrain navigation. Each exercise follows the same format: a map study period, the actual exercise, and a flight debrief. Students are provided with laminated copies of the DMA 1:50,000 contour where the route is flown. The map study period covers specific considerations for the type of terrain covered. Specific considerations such as "in arid regions, water ways are

more significant so are depicted more frequently" are covered. After the map study, students are tasked with the flight exercise. During this part, a video taken from a helicopter flying a navigation route over the terrain is shown. The video is taken from a UH-1 and is shown at approximately twice normal terrain flight speeds. Students use grease pencils to mark the progress of the helicopter and identify checkpoints. Students are alerted that the aircraft is approaching a checkpoint with the text message "Ready N" where N represents the checkpoint number. This message is displayed approximately 5 seconds prior to arrival at the checkpoint. The only other feedback during these flight segments is the aircraft heading. When the helicopter turns, the new heading is flashed on the screen briefly (approximately two seconds.) The video is not stopped at any time during this phase. The final phase is the flight debrief. This phase repeats the fly-over video sequence, pausing at critical points to point out what students should have been noting.

Although MITAC is an excellent familiarization tool, the media it relies on has severe limitations. These limitations restrict the quality of training possible in even the best systems. Video Home System (VHS) is inherently not interactive. It is also designed for narrow field of view. These features inherently conflict with training helicopter navigation. Helicopters rely on field of view for navigation; effective training requires interaction and feedback. These inconsistencies were cited as one of the reasons the MITAC is often not incorporated into the CSAR ground school. One instructor noted the opportunity for negative training transfer (HS-10, 1998):

> *Since the video moves so fast and has such a narrow field of view, students can only navigate by picking one feature from directly in front and well ahead of the aircraft. It's the only way they have time to look down at the map to find this feature in time to look up again. This means they're totally ignoring what's happening on either side of the aircraft. ... I think students might be better off without MITAC.*

Although MITAC provides a vague familiarization with terrain navigation, the media is intrinsically incompatible with effective helicopter terrain navigation training.

F. HAMMERING THE SCREW

Can existing or emerging technology eliminate or reduce the problems associated with helicopter terrain navigation? Perhaps by adapting existing training or rehearsal systems or improving cockpit navigation aids, we could eliminate the need for map interpretation and terrain association skill training. Unfortunately, improved navigation aids cannot eliminate the need for this basic skill, and existing systems were not designed to accommodate the unique training requirements for helicopter terrain navigation. Adapting existing tools to the helicopter terrain navigation training may be similar to using a hammer to drive a screw: marginally effective and grossly inefficient.

1. Adapting Current Virtual Environment (VE) Applications

The Navy and Marine Corps have invested heavily in VE systems. Perhaps current systems could be adapted to fill this role. The Navy and Marine Corps currently have two real-time fly-through systems available for training: conventional flight simulators (or motion based trainers (MBTs)) and a recently developed mission rehearsal system by Mires Corporation – TOPSCENE. Neither of these systems were developed to support helicopter overland navigation, thus both systems are severely limited in their ability to provide the fundamental elements required for effective training.

a. Accessibility

There are currently 27 TOPSCENE systems available for use by the DOD. Because of the limited number of systems available, they are reserved for front-line units; deployed ships and final stage pre-deployment training units. Within these units, access is severely limited. Approximately 120 pilots in eight different squadrons share one TOPSCENE system on an aircraft carrier. Obviously, without substantially increasing the inventory of TOPSCENE systems, access at training commands and at non-deploying units is impossible.

Access to Navy and Marine Corps MBTs is also extremely limited. For the HS community, there are two MBTs. A wide variety of interests compete for use; consequently time in these simulators is a precious commodity. These interests include the Fleet Replacement Squadron (FRS), fleet squadrons, and reserve units. The FRS uses

the simulator for both students and staff-members. A major portion of students' initial training is performed in these trainers. Reserve units rely heavily on the simulator for practice instrument meteorologist condition (IMC) flight practice as well as annual instrument and Naval Air Training and Operating Procedures Standardization (NATOPS) qualification flights. Fleet units use the simulator for weapons qualification training prior to each in-flight weapons exercise. Over the past five years, simulator utilization rates have remained roughly 90 percent (Taylor, 1998). If the simulators could be augmented to fill the role of navigation training, limited availability would make them nearly useless. Conducting navigation training on such comprehensive systems may not be a financially viable solution. If the same training could be accomplished separately, full-mission oriented systems could be reserved for their designed use.

b. Inadequate Display Capability

Based on the nature of helicopter flights outlined in Section II.D, field of view is critical to helicopter terrain navigation training. In fact, the importance of peripheral view when related to navigation is explicitly stated in (CNO, 1992, p. 13-4):

> *For terrain navigation, use is made of both the central and peripheral visual fields, but the peripheral is the decisive field.*

An effective terrain navigation system should have appropriate field of view and resolution to support peripheral vision. Neither TOPSCENE nor the SH-60 MBT provide appropriate visual display for use as effective navigation training tools.

The field of view of the current training systems is depicted in Figure 11 and Figure 12. For comparison, the field of view possible using a three-screen configuration, like that used in this implementation, is shown in Figure 13. The highest-end TOPSCENE unit uses a 24-inch monitor to display roughly 40 degrees field of view. The H-60 cockpit has roughly 160-degree field of view (Sikorsky, 1987). Given the importance of field of view for navigation, TOPSCENE would seem to fall short as a training system. Although the MBT has a wider field of view, neither the quality of the graphics display nor the terrain modeling supports terrain navigation (HS-10, 1998). The SH-60 MBT supports several ambient light levels. The highest of these is "twilight". These light settings provide sufficient visual cues for landings on airfields and aircraft

carriers. They do not provide sufficient visual cues to support terrain navigation. Additionally, there are no terrain models associated with the simulator. All landforms are assumed to be flat. The only land areas accurately modeled are airfields. Without significantly improving the quality of the graphics display and incorporating the ability to load accurate terrain models, the MBT is not useful as a terrain navigation training system.

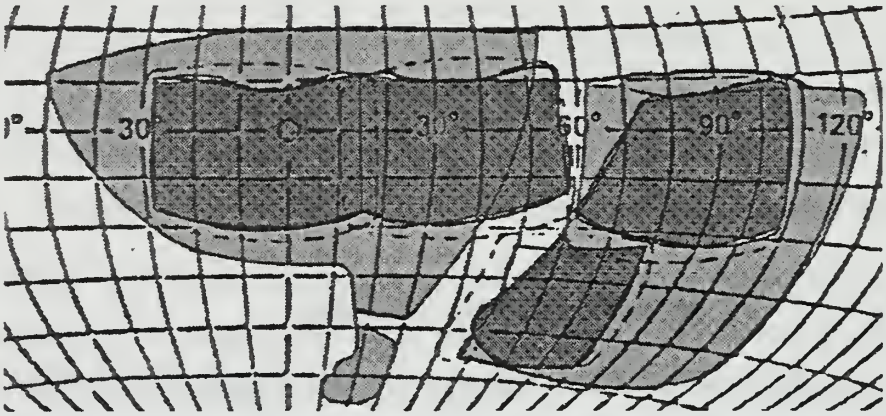

Figure 11. Field of view available in aircraft (light gray) compared to motion-based trainer (dark gray). Adapted from (Sikorsky, 1989).

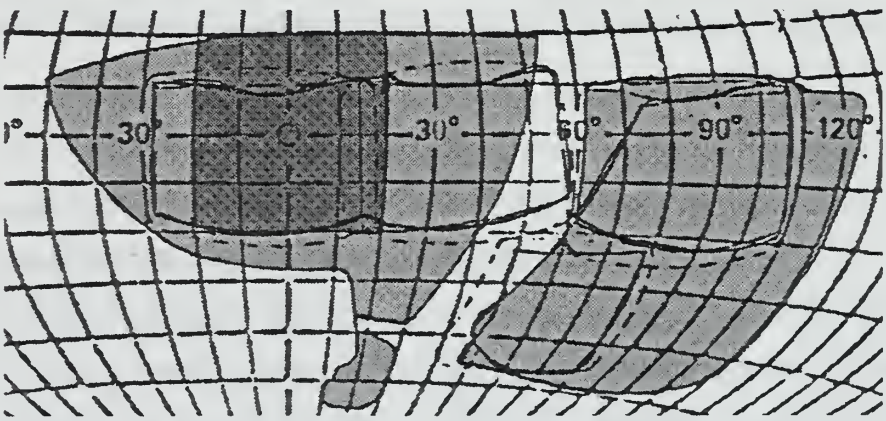

Figure 12. Field of view available in SH-60F (light gray) compared to TOPSCENE (dark gray). Adapted from (Sikorsky, 1989).

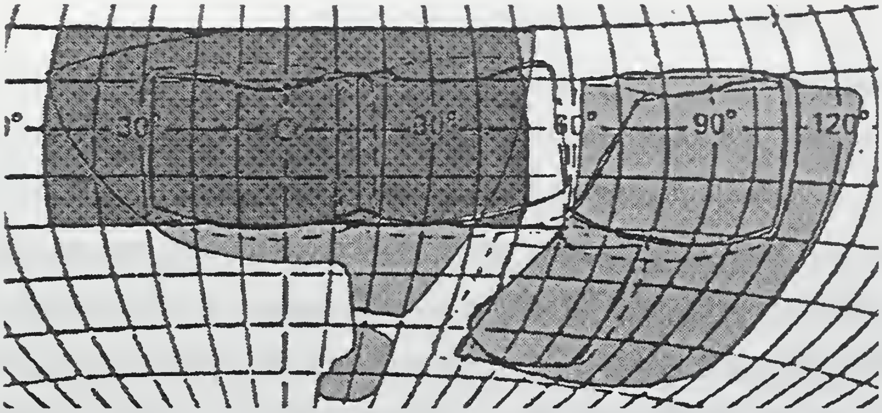

Figure 13. Field of view possible using a three-screen configuration (dark gray) compared to field of view available in SH-60F (light gray). Adapted from (Sikorsky, 1989).

c. *Inadequate Modification Capabilities*

Changes and updates to larger systems tend to be expensive and time consuming. In 1991, the Navy contracted an upgrade to the graphics system for the H-60 MBT. Over the next four years, the Department of Defense spent over 25 million dollars for an improved visual system. As of August of 1998, the visual system has not yet been upgraded (E. P. Taylor, personal communication, August 16, 1998). Obviously, such larger-scale systems are not conducive to reconfiguration based on student and instructor needs.

d. *Lack of Validation as a Trainer*

Are current systems effective for terrain navigation? Based on the graphics quality and terrain model features discussed in Section II.F.1.b, the MBTs cannot be considered as viable terrain navigation trainers. TOPSCENE, however, has many of the same characteristics as a terrain navigation training system. Although it has been widely acclaimed as a mission rehearsal system for fixed wing aircraft, TOPSCENE has not been used or evaluated as a navigation training system. Before adapting an existing system, the effect of individual components should be measured, evaluated, and if necessary, adjusted. What type of feedback is required to ensure improved navigation performance? Any investment in a training system must first answer this question.

2. Improved Cockpit Navigation Aids

Improved cockpit navigation aids are vital and necessary. However, they do not replace the need for basic terrain interpretation skills. If crewmembers lack the ability or confidence to navigate for extended distances without reference to cockpit displays, the navigation task will draw excessive attention away from other crucial tasks. An ideal moving map integrated into a HUD system cannot suggest to a pilot the best tactical use of the terrain between his/her current location and destination and requires excessive attention to update, change, or verify. Navigation aids such as Global Positioning System (GPS) are effective at providing current location and destination information, but are weak at path planning. Additionally, changing and updating electronic navigation aids draws pilots' attention into the cockpit. In the terrain flight environment, cockpit maintenance functions diminish the ability of the non-flying pilot to effectively back up the flying pilot on critical tasks such as obstacle clearance. The simple act of verifying the degree of confidence in a GPS signal could divert a pilot's attention from a utility line. Tactical path planning relies on map interpretation. Electronic aids can indicate present position and destination, however, they cannot indicate the best path to get there. The fundamental skill of map interpretation cannot be replaced by navigation aids.

III. APPROACH

A. OVERALL SYSTEM GOALS

This project originated as conversations between subject matter experts in current USN and USMC helicopter training techniques and subject matter experts in VEs and navigation training. The initial efforts of discussion and research were refined based on interviews with current subject matter experts on helicopter navigation training and members of the target user group. Interviews were conducted at HS-10 at Naval Air Station North Island (NASNI) over a two-day period with groups of IPs and Fleet Replacement Pilots (FRPs). During this period, current training deficiencies, the capabilities of VEs, and effective navigation training techniques were discussed. This closed loop development cycle may be one of the most significant aspects of this project. The results and conclusions reached by the group guided project development and are described in this section.

1. Wide Field of View Interactive Fly-through

The model of spatial knowledge and the results of recent attempts to clarify the role of VEs in improving navigation skill outlined in Chapter II help clarify the basic features of a terrain navigation training system. Based largely on the results of Lintern and Wickens (1992) described in Chapter II, developers assumed that real-time active control of a window to the world simulation is the most appropriate means to improve navigation performance. The nature of helicopter navigation and the summary of the shortcomings of current systems outlined in Chapter II highlight the importance of a wide field of view. Based largely on the input of terrain navigation subject matter experts (CNO, 1992; HS-10, 1998), developers assumed that, to the maximum extent possible, the simulation should present the same field of view available in the aircraft (approximately 160 degrees). Therefore, the trainer should provide wide field of view, real-time active control of a window to the world or fly-through application.

2. Not a Literal Recreation of the Task

It is extremely expensive to accurately recreate real-world conditions in training systems. Less expensive systems sacrifice the degree to which objects and user's interactions with the objects resemble real-world conditions. However, many of these less expensive systems are capable of object manipulation that is not possible in the real world. One of the fundamental strengths of VE systems is the ability to provide numerous, tailored, alternative representations and interactions with environments. An effective training system should not attempt to literally recreate helicopter terrain navigation. It should attempt to exploit the capabilities of VE systems to provide alternative representations. These alternative representations should be based on our current understanding of effective map reading and terrain association training and spatial knowledge acquisition.

3. Training, Not Rehearsal

Initially, this training system was developed to support rehearsal for training flights. The training route used on navigation flights was recreated in its entirety. The assumption was that the simulator should recreate the task in the aircraft and provide students the opportunity to train the same route they would eventually fly. The weakness of this assumption was brought out during the interviews with IPs at HS-10 (HS-10, 1998). After further discussion, it was also determined that this assumption was not consistent with principles of spatial knowledge acquisition outlined in Chapter II.

Instructors at HS-10 felt strongly that the most appropriate goal of a computer based terrain navigation training system should be generalized terrain navigation skills. Specifically, the tool should improve a user's ability to conduct terrain navigation anywhere, regardless of type of terrain or route flown. This is a vastly different focus than route preparation. Instructors pointed out that recreating training routes would not necessarily improve the navigation training course. If the same route was used in the trainer and aircraft, the problem of stale training routes (discussed in Chapter II) would be compounded. If students received exposure to the training route prior to aircraft events, they could complete aircraft events based on landmark recognition rather than terrain interpretation (HS-10, 1998).

4. Part-Task Training

As discussed in Chapter II, VEs developed for flight training applications have been focused on high-end systems. These systems are designed to accurately recreate as much of the in-flight environment as possible. To be effective, they need to faithfully recreate system dynamics with an extraordinarily high degree of fidelity. This requires expensive hardware and software. Consequently, acquisition and modification of these systems is extraordinarily difficult and time consuming.

To support asynchronous access, the proposed training system must be able to run on smaller, more affordable systems that can be easily updated. Desktop systems cannot currently provide the computational power required to faithfully reproduce the flying environment. Additionally, the software development cycle required for high fidelity modeling is extremely prolonged. Modifying such a system would also be a lengthy process. Thus, current hardware and software limits the fidelity of what can be produced and thus the degree to which the entire flight task can be trained on a single system.

Even if it could affordably be accomplished on desktop systems, it is not necessarily best to try to train the whole mission. This notion is supported for general training as well as for a system designed to provide measurable improvement. If a system were designed to provide improvement in aggregate skills, it would be extraordinarily difficult to measure the effect of changes made to the trainer. Researchers would have a difficult time attributing improved performance to changes made to the training system. A trainer that focuses on one skill more readily lends itself to analysis and thus effective adjustment.

Based on the above discussion and the principles of part-task training discussed in Chapter II, the original focus of the training system shifted from route preparation to general terrain interpretation skills. Since the goal is to improve overall navigation performance, the basic concept of a fly-through application was maintained. The primary shift involved the terrain model and the routes through this model. The optimal system should not involve the same training area and routes that will be used on aircraft events. In an initial implementation, it may be appropriate to model the same type of terrain, but the same routes used in the aircraft should not be used in the trainer. The tool should eventually provide access to a variety of terrain types.

5. Asynchronous Access

Based on the discussions with the IPs at HS-10, it was concluded that a vital component of the system is easy access. Easy access in this context is defined as both physically present, easy enough to use that it does not require a system administrator, and optimally requires no training. The ideal system would be self-explanatory. A common complaint about current VE applications (specifically tactical air mission planning system (TAMPS) and TOPSCENE) is the need for a system administrator and lack of ready physical access to the system. Instructor Pilots and FRPs felt strongly that the trainer should be available for basically unlimited access. Every individual has a different level of initial skill and learns at a different rate. All those interviewed believed that with the proper feedback from the system, individuals could asses their own ability and determine when and how to use the system. In their view, the ideal system would not necessarily be considered a computer but rather as a training resource. Ideally, the system would require no training manual, no system administrator, and only one interface device: a flight control (HS-10, 1998).

B. DISPLAY DEVICE DECISIONS

There is very little research that delineates the type of display that is appropriate for a given training task. In lieu of extensive research, this project applied common sense to a common problem. The choice of display device was driven by two requirements of the system: It had to be easy to learn, and it must provide a wide field of view. The need for wide field of view and a simple interface is outlined in Chapter II. Two systems that offer a wide field of view were considered: a helmet mounted display (HMD) and a multiple monitor display. Immersive CAVE-like displays were not considered because of cost and portability issues (Cruz-Neira, Sandin & DeFanti, 1998). Single flat panel displays were not considered because they cannot provide adequate field of view. Based on currently available devices, a multiple monitor display was viewed as the superior display device for the task of terrain navigation training.

1. Advantages of Head Mounted Displays

Head mounted displays have several important advantages. Primarily, they support a natural interface with access to unlimited field of view. Although HMDs present approximately 30 degrees field of view, when connected with a head-tracking system, users can easily access potentially unlimited field with the simple, natural act of head turning. The ability to look up and down, left and right without restriction greatly simplifies the interface and thus the time to learn how to use the system.

Head mounted displays are less expensive in terms of the field of view they allow the user to access. Providing a 360-degree horizontal and vertical field of view with any other display technology is not practical. Additionally, HMDs occupy a very small footprint. This is a particularly attractive feature of a system designed for use by deploying units. Head mounted display devices are much easier to move, setup, transport, and store than other display devices.

A potential advantage of HMDs is the positive training effect gained from forcing students to move their head. This is particularly significant considering Night Vision Goggle (NVG) training. Current fleet standard Aviator Night Vision System Six (ANVIS-6) NVGs have a 40 degree field of view. In the night terrain flight environment, it is critical that pilots continually scan the horizon. Although this effect has not been validated, intuitively, the nature of HMDs would support this notion.

2. Disadvantages of Head Mounted Displays

Several features of current HMDs make them incompatible with terrain navigation training. More than other display devices, HMDs are widely attributed with simulator sickness. Not only does simulator sickness generally reduce the effectiveness of a training system, it also could impact scheduling. This conflicts with one of the system's primary goals stated in Section III.A: supporting asynchronous access. Current doctrine prohibits pilots who are prone to simulator sickness from flying within 12 hours of completing a motion based simulator event. A training system that incorporates an HMD and is designed to be available to all pilots without prior coordination with unit scheduling personnel would create scheduling conflicts. The issue of motion sickness and

a 12 hour waiting period would be particularly problematic if the implementation migrated to a mission rehearsal system.

Head mounted display systems are not widely implemented onboard Navy ships and in other Navy commands. Therefore, initial acquisition and parts support would be troublesome. While low-end HMDs are less expensive than computer monitors, they cannot generally be used interchangeably with other computer systems. An HMD cannot double as a display device for a squadron's administrative computer system. Additionally, shipboard implementation, including both the physiological effect on users and the electromagnetic interference of the ship, have not been fully evaluated.

Another concern is the effect a new display technology may have on a training system. Part of this effect may stem from the degree of familiarity and comfort users have with the technology. Very few fleet aviators can be expected to be familiar with HMD systems. It is very likely that this would be their first experience with extended immersive exposure to synthetic environments. If the target audience is not familiar with the technology, they may not be comfortable with it. This lack of comfort and trust is one reason the display technology may have a separate effect on the overall training system. This effect could only be measured by conducting separate experiments or by creating different implementations and setting each up as a separate trial. While the intent is not to rule out technology because it has not been previously implemented, prior validation of the display media is viewed as a separate and prerequisite step. Initial validation of immersive technologies prior to implementing and testing a navigation training system is beyond the scope of this work.

Perhaps one of the most compelling arguments against incorporating an HMD into a navigation training system is the degree to which it complicates access to an essential reference; the paper contour map. During trials, subjects had difficulty maintaining orientation in the virtual environment when they tried to cross-reference the viewed scene and the paper map. Generally, subjects' initial tendency was to tilt their head down to look at the map. Obviously, with head tracking, this changes their viewpoint in the scene. The user therefore must condition him/herself to maintain head position and use eye movement only to look under the display device down to the map. This proved to be unnatural, disorienting, and provided at best a marginally adequate

view of the paper map. A possible solution to this problem is to eliminate the paper map and make it available digitally within the HMD system. Such a system would require much better display resolution than is currently available and a validated interface that is as easy to learn and as effective as looking down to reference a paper map. Creating an interface within a HMD that provides the desired ego and exocentric views, feedback mechanisms, and incorporates a mechanism that replaces references to a paper map is considered beyond the scope of this work.

3. Advantages of Multiple Monitor Displays

A multiple monitor display or video wall configuration has several advantages. Primarily, the wide field of view provides the peripheral view that (CNO, 1992) points out is critical to navigation (discussed in Section II.F.1.b and depicted in Figure 13). Additionally, it relies on technology that the vast majority of intended users are familiar and comfortable with. There is minimal chance that users will be intimidated by or have a hard time adjusting to the display medium. For final implementation, this supports the goal that the system must have minimal learning curve. For experimentation purposes, it minimizes the chance that measurements on the effectiveness of training will be impacted by any effect of a new display medium.

Monitors are part of virtually every unit's equipment inventory. Acquisition and repair parts support for systems that rely on computer monitors is greatly simplified. Additionally, the monitors used for this system could also be used for other unit computing needs. Monitors used in a terrain navigation system could also be used for other squadron administrative roles. This helps minimize the negative impact of the large footprint a video wall requires.

One of the primary advantages of a video wall system is that it is supports the ability to cross-reference the viewed scene in a synthetic environment with a paper map. It is relatively simple to configure display monitors and input devices in a manner that allows the user to position a paper map for ready reference. The physical setup is analogous to how the task will be performed in the aircraft. Compared to other wide field of view displays, including HMDs and CAVEs, relatively few video walls have incidents of simulator sickness. The incidence of simulator sickness from monitor–based displays

is lower than that of HMDs. In addition to the obvious benefits of more comfortable use and less distraction, this helps support asynchronous access. As mentioned in Section III.B.2, display devices that promote simulator sickness can cause scheduling problems.

4. Disadvantages of Multiple Monitor Displays

Multiple monitor or video wall displays have several drawbacks. They require a large footprint and are cumbersome to transport, store, and setup. The display area is not continuous (because of the monitor borders) and they require complicated interfaces if they allow control of both motion and viewpoint orientation. Despite these disadvantages, based on current technology, they are viewed as the superior choice for this application.

Adding monitors to a display creates several problems. Central among these for deploying units is the large footprint they require. In space-limited environments, room for additional monitors is not always available. Additionally, transporting and setting up the display is significantly more difficult. The fact that the monitors can be used for other applications somewhat minimizes but does not eliminate this problem.

Based on currently available technology, multiple monitor displays cannot provide continuous field of view. When monitors are configured side-by-side the monitor casings create a large gap in the viewable area. While display devices with no or minimal borders are available, they are prohibitively expensive. Simulations that recreate a window to the world on monitors cannot easily recreate natural scanning habits. In the aircraft, it is natural to scan left and right to compare features around, as well as in front of, the aircraft. Recreating this motion when monitors are used is extremely difficult. The developer is left with the choice of fixing the orientation or providing an interface that controls not only vehicle motion but viewpoint as well. These eye-in-hand metaphors allow tremendous amount of flexibility in how the model is experienced. However, this also increases both the time it takes to learn the interface and the attention the interface draws away from the primary task. Because of these factors, a controllable viewpoint was not incorporated.

C. LOCOMOTION INTERFACE DECISIONS

Based on the discussion in Section II.C.2, it is clear that we want to provide an egocentric window on the world of a terrain model and an interface to control motion through the model. This section discusses the best interface to control vehicle locomotion.

A primary consideration in devising this locomotion interface is how well it supports the goal of the training system. Another prerequisite of the interface is that it is easy to learn. Both of these must be balanced to achieve best possible experience with the VE. Quality of experience is measured by the degree of improvement in the user's general navigation skills and, more specifically, their ability to associate terrain features and their contour map representation. Broad and general assumptions about the locomotion interface were made. The interviews with HS-10 staff and students (HS-10, 1998) provided validation and correction to these initial assumptions. These assumptions and corrections are outlined below.

1. Limitations of Literal Helicopter Models

Adhering strictly to a helicopter model does not reasonably recreate the training task. It is difficult to do well, involves substantial computational overhead, may increase the chance of negative training transfer, and unnecessarily restricts the user's experience with the VE. For these reasons, a physically-based helicopter model was abandoned. The final implementation incorporated a semi-automated helicopter-like vehicle. This vehicle was not restricted by the aerodynamic limitations of helicopters. This section contains a description of the rationale behind the capabilities included in this model.

Overall Characteristics
Helicopter based
No aerodynamic modeling
Linear mapping of control displacement to rate of change
Egocentric pitch and roll not modeled
Heading Control
Automatic heading control
Consistent turn rate
Turn rate greater than aircraft
Speed Control
Easy to set and maintain ground speed
Allows forward and reverse motion
Allows access to greater speed than aircraft
Altitude Control
Easy to set and maintain altitude
Automatic terrain following
Automatic minimum altitude enforcement
Climb rates better than aircraft

Table 2. Features of ideal locomotion interface.

a. Virtually Impossible to Accurately Recreate Task

As outlined in Chapter II, helicopter navigation is a crew evolution. While navigation is the primary responsibility of the non-flying pilot, each crewmember has a role in this task. Similarly, terrain avoidance is the primary responsibility of the flying pilot and each crewmember, particularly the non-flying pilot, has a role in this task. One pilot would never be tasked with both control of the aircraft and navigation. This scenario is exactly what the training system is designed to provide: a situation that should never happen in the aircraft. This was one of the reasons that a physically-based model of helicopter dynamics was abandoned and the task of flying simplified.

b. *Increases Potential for Negative Training Transfer*

Implementing a physically-based model of a helicopter may lead to negative training transfer. If there is a strong association between flying the aircraft and moving through the model, the user is more likely to repeat flying techniques learned in the simulator when in the aircraft. This would detract seriously from the part-task nature of this training system. Consider the quick stop described in Section II.C.1 and depicted in Figure 10. During this maneuver, pilots are trained to use peripheral vision to judge and maintain constant obstacle clearance about the tail skid. Without a fully immersive dome trainer, this peripheral view is not available. Additionally, if a physical model did not include the proper response, the student may be more likely to perform this maneuver incorrectly in the aircraft.

c. *Requires Excessive Attention*

If it did happen to be possible to accurately recreate the task of airborne navigation, it would not necessarily help the training process. Students as well as instructors concurred with this assumption. Not only would this substantially increase the time to learn to use the system, it would allow users to devote less attention to the primary task. One of the particularly troublesome aspects of this relates to the nature of helicopter navigation outlined in Section II.C.1. The navigation task is dramatically different at 50' AGL than it is at 200' AGL. Navigation at 50' is much more difficult than at 200' AGL. If the aircraft were faithfully reproduced, then the physical act of flying should also be more difficult at 50'. Thus, both the workload associated with navigation and the workload associated with flying increase at lower altitudes. Accurately recreating aircraft characteristics would draw more attention away from the task of navigating in regimes where navigating requires the most attention.

d. *Annoying if it Only Gets Close*

The closer an interface comes to approximating flying, the more annoying it will be that it does not *exactly* replicate flying. Generally, users are comfortable with one extreme or the other, and considerably less comfortable as the approximation nears but fails to reach a perfect match. Perhaps this is a matter of the degree of trust and

resultant disappointment invested in the system. As users interact with a simulation, they 'buy into' the synthetic nature. If pilots rely on the simulator and assume it will respond exactly as the aircraft does, they will devote less attention to the physical act of flying and rely more on subconscious habit patterns. When this pattern is disturbed by inconsistencies between the simulator and the aircraft, the attention scheme is disturbed, and the pilot must devote more attention at the expense of the training task. When this happens randomly and unpredictably, the user is more likely to be annoyed than if they were challenged with learning a new and dissimilar flight control interface. Regardless of the reason, it is clear from interviews that the interface should either exactly correspond to the aircraft's flight control system or not all.

e. *Excessive Computational Overhead*

Accurate modeling of helicopter dynamics is computationally intensive. Desktop VE systems cannot currently support this computational load without sacrificing frame rate or scene detail. In this implementation, frame rate and scene detail are considered at the lower limits. Adding computationally intensive modules would drop frame rate below acceptable limits. Accurate aerodynamic modeling and acceptable frame rate would require improved hardware and reduced scene detail.

f. *Unnecessarily Limits Experience With VE*

One of the primary strengths of VE technology is the ability to provide flexible representations of a model. There is no empirical reason that these representations should be limited by the physical constraints of the real world. For example, to compare the view from a point on a map at two different altitudes is difficult in the aircraft. In a virtual model, access to this capability could be provided easily. To capitalize on the strengths of VEs, it makes sense to allow capabilities beyond the limitations of the real world. Thus, several extraordinary capabilities were explored and ultimately incorporated. These are discussed at length in the following section.

2. Designing Augmented Helicopter Maneuver Capabilities

The original concept of helicopter motion was modified based on the discussion in the previous section. The helicopter's capabilities were augmented to enable access to the flexible representations of a model that computers can easily generate. A detailed discussion of the methods to implement these interfaces is included in Chapter IV. Table 2 outlines the conclusions reached in this section.

a. Heading control

Heading should be controlled by a straightforward linear mapping of control displacement to rate of turn. The model's rate of turn should be consistent regardless of airspeed. In the aircraft, control inputs have greater effect near the extreme ranges. Rate of turn is proportional to angle of bank and airspeed. If we attempted to model this, students would have to learn how the model responds over a wide range of airspeed/angle of bank combinations. The time to learn this could be spent on terrain association.

Egocentric roll and pitch should not be modeled. Although the basic metaphor of a helicopter is followed, maneuvering the model should not alter the view as it would in a literal interpretation. During initial trials, motion models that included pitch and roll were evaluated. These were based on the default vehicle motion models provided in Silicon Graphics Incorporated (SGI) utility modules. In a literal interpretation, if the user turned right, the helicopter would roll right about the longitudinal axis. Following this scheme, the view of the world would apparently roll left. When a finite window to the world (anything less than that available in the aircraft) is provided, this proved to be very distracting. Particularly, the limited vertical field of view causes items of interest to disappear from view during turns. Altering the viewpoint's orientation about the longitudinal axis tends to be disorienting, leads to simulator sickness, and thus is not conducive to comparing terrain features with their map representations. Therefore, maintaining a fixed orientation about the longitudinal axis is assumed more conducive to improving terrain association skills.

b. Altitude Control

Altitude control should involve a linear mapping of control displacement to rate of climb. Rate of climb should be greater than aerodynamic and power limitations of the aircraft allow. Terrain following and automated minimum altitudes should be included to reduce pilot workload. At constant airspeeds, helicopter climb rates vary with temperature, humidity, aircraft weight, and aircraft power setting. The kinetic energy of forward airspeed can be traded for altitude. Modeling these dynamics would increase the user's workload and impose restrictions on motion. This would degrade the potential of the VE experience. Consider the student who wants to maintain a constant position over the ground and view the terrain from 50' AGL and 400' AGL. In the aircraft this would be an extremely labor intensive maneuver. A straight vertical climb in the aircraft is aerodynamically precarious, demands high power and has very low margin of error. Controlling the aircraft through this maneuver requires a great deal of attention. If the trainer accurately modeled helicopter aerodynamics, it is unlikely that the user would have adequate attention to devote to viewing both the scene and the contour map. Therefore, an ideal interface should incorporate a technique that simplifies altitude control.

c. Speed Control

Speed should be easy to control and maintain. The interface should allow the user to set a constant speed. Once this speed is set, the model should maintain this speed without additional user input. The model should have the ability to move backward as well as forward. Maximum rate of movement should be the same in both directions. Access to speeds beyond the capability of the aircraft may improve the VE experience and reduce training time.

The ideal control mechanism for speed would involve mapping control displacement to rate of travel. The best type of control would not have an automatic centering mechanism (when released, the aircraft stops). A device with an automatic centering mechanism would require pressure and thus attention to maintain a constant speed. A neutral detent in the position corresponding to zero motion would allow the

user to stop the vehicle based on tactile response only. This low-maintenance technique of stopping the model would be very conducive to moving freely through the model.

Detents on the extreme ranges of control travel could be used to access speed capabilities beyond normal helicopter limits. This scheme would allow users to exploit capabilities of the VE and provide clear indication when they are doing so. If there is no clear indication that normal limits are being exceeded, the user may not realize they are no longer operating in a regime that can be recreated in the aircraft. When users are unaware that they are exceeding speeds available in the aircraft, they may unknowingly increase the degree of difficulty of the task and hinder the training process. This is particularly important considering the lack of peripheral cues to judge rate of motion available in simulation systems.

3. Initial Evaluation of Helicopter Control Metaphors

Two modes of vehicle control were implemented and investigated. The first mode roughly followed a helicopter's flight control system. The second mode roughly corresponded to a fixed wing aircraft's flight control system. The modes differed in the means of speed and altitude control. Both modes shared a common heading control mechanism. Lateral displacement of the longitudinal flight control was mapped to turn rate. After studying a wide range of subjects and tasks, the fixed wing mode was selected over the helicopter mode. Although this did not conform to the majority of user's expectations, it more effectively supported terrain navigation training.

a. Fixed-Wing

Mode one approximated fixed-wing controls. Pushing the throttle forward increased forward speed. Pulling the throttle back increased rearward speed. The neutral position corresponded to zero speed. The stick responded as a fixed wing primary flight control. Pushing forward caused the model to descend, pulling back caused the virtual aircraft to climb. With the stick in the neutral position, the virtual aircraft maintained straight and level flight.

b. *Rotary-Wing*

Mode two approximated helicopter controls. The throttle responded like a collective. Pulling the throttle device back toward the user caused the model to respond as if the collective were raised; the virtual aircraft climbed. Pushing the throttle forward was the same as lowering the collective; the virtual aircraft descended. The middle position on the throttle corresponded with neutral collective - collective required to maintain straight and level flight. The stick responded something like a cyclic. Pushing the stick forward increased model forward speed. Pulling back on the stick increased reward speed. The neutral position (laterally and longitudinally centered) resulted in zero speed.

c. *Preliminary Results*

Although most helicopter pilots expected a throttle device to respond like a collective, the fixed wing flight control mechanism supports the task of terrain navigation training better. This result suggests that adopting an interface that requires some degree of adaptation may result in improved training. Altitude selection and maintenance was adequate with both models. However, the fixed wing style control of airspeed made it easier for users to set a fixed speed and maintain it. This method allowed users to take their hands off the controls and attend to the primary task; resolving terrain features and their map representations. This concept was supported during intial test and is discussed in Section VII.A.2.

D. FEEDBACK

Determining the type of feedback that is appropriate and how it should be accessed is a topic worthy of several theses. In lieu of extensive research, several major assumptions were made. These assumptions were then verified and adjusted based on interviews with the subject matter experts (HS-10, 1998) and usability studies. During these interviews, a variety of interface and training techniques were presented. Additional thoughts and rank ordering of all methods were solicited. This section

contains a discussion of various proposed feedback mechanisms, and the rationale for prioritizing inclusion of each.

1. A You Are Here (YAH) Map and Own Ship Track

Simply providing a controllable viewpoint in a VE does not ensure that an individual's terrain association skills will improve. Clearly, users need a means of re-orienting themselves or otherwise verifying their position. Without feedback that allows users to assess their performance, the training tool would be of questionable value. One of the most straightforward means to provide this feedback is with a You Are Here (YAH) map. Some of the principles discussed in Section II.B.2 provide useful guidelines for implementing the YAH map.

Instructors felt strongly that a YAH map should be included. They felt it was a necessary reference in an effective training system. They felt the YAH map should be a completely separate entity and not a replacement for the paper map. This would keep the task similar to that which will be performed in the aircraft where navigation is performed primarily by reference to a paper map. The YAH map then would be used primarily to verify or relocate the position of the model on the paper map.

Instructors also believed the map display should adhere to the basic principles of navigation demonstrated by Aretz (1991). These principles are strongly supported by the discussion in Section II.B.2. Key among these principles is that the map should always be centered on the model. And since this is primarily an egocentric task, the map should also always be oriented to align with the heading of the model (Cevik, 1998; Harwood & Wickens, 1991). Both the instructors and students demanded little else from the YAH map. Some rudimentary ability to zoom in and out and basic track information were the primary augmentations requested for the map.

Adding the ability to depict a variety of routes would improve the overall training system. Instructors were interested in the ability to tailor and redefine routes. Likewise, students were interested in trying out multiple training routes, preferably with varying levels of difficulty. Users felt it would be useful to include the ability to erase their track. This tool would be most useful when users were repeating routes or circling a point.

Providing a YAH map that is always in view may impede the training process. If the map is always present, users may tend to rely on the map as a primary navigation aid. The map could be a performance aid, not a training aid. If egocentric motion is allowed while the map is displayed, users may become dependent on alternative displays. Subsequent performance during training flights may actually decline after exposure to the training tool. As indicated by Cevik (1998), clearly, a YAH map implementation should be moded or users will stop looking at the forward view and rely entirely on the map. To avoid the possibility of data dependency discussed in Section II.A.2.g, when the YAH is displayed, egocentric motion should be disabled.

2. Exocentric View

Based on the work of Wickens (1992) related to exocentric views (views external to the helicopter model) for navigation training in VEs, the development team discussed incorporating access to an exocentric view. Both IPs and FRPs viewed this feature as highly desirable (HS-10, 1998). Several schemes for incorporating this view were considered. One of the first schemes discussed, and subsequently ruled out, was a separate display area that provided a controllable wingman view. A very rough prototype of this concept is depicted in Figure 14. Instructors felt this could create a dependency that could hinder the training process. Students may rely on this view too heavily and actually perform worse in the aircraft where the tool would no longer be available. The development team also felt that it was too difficult to divide display space to provide access to a separate viewing window, and too difficult to learn how to appropriately divide attention between the separate views. If the views were provided simultaneously, users would have to scan from the paper map to the forward view and to the wingman view. Although the alternative representation may be helpful, it would certainly take some time to learn how to resolve the three sources of information into one coherent mental image. Additionally, if the window were always in view, it would obscure potentially vital features from the forward view.

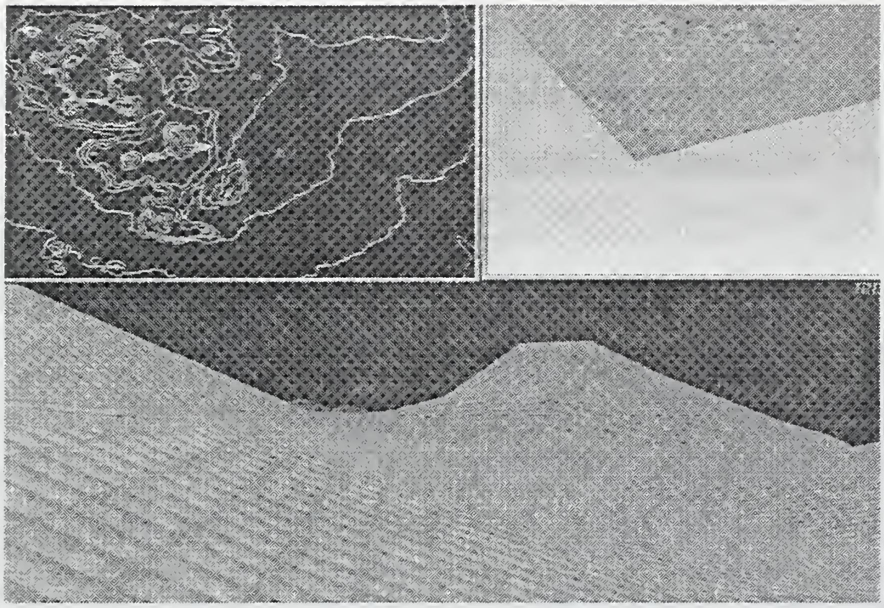

Figure 14. Prototype terrain navigation trainer incorporating three representations of the terrain.

A variation on this scheme was also discussed. It eventually provided the final guidelines for implementing the exocentric view. In this implementation, the view would be selectable and moded, similar to the YAH map described in the previous section. Unlike the YAH map, however, resolving the scene would not be simple and straightforward. Presumably the exocentric view is provided to help resolve ambiguities among terrain features. When the exocentric view is presented, how do users identify the features they are trying to distinguish? This problem derives from teleportation issues. If the viewpoint is moved an arbitrary amount to a distance from which the user can no longer recognize terrain features, they must first take time to resolve features from the new vantage point. For students learning or practicing the skill, this sudden transformation may prove too difficult. Based on these factors, a selectable wingman view in a separate display area was determined to be detrimental to the training goals.

From this information, it seemed clear that access to the exocentric view was important but difficult to implement properly. Access to an exocentric view should be moded and the viewpoint should move consistently when this view is accessed. If a camera metaphor is used, the interface should behave as follows. Normally, the camera is inside the vehicle that the user controls. When the user wants to access the exocentric

view, they no longer control the aircraft, they are now controlling the camera itself. To maintain a consistent view, the camera should always remain centered on the aircraft.

3. World-In-Hand Metaphor

Access to a world-in-hand metaphor could provide tremendously valuable terrain association training. Although this feature was ranked below access to the YAH map and exocentric views described in the previous two sections, this feature has a great deal of intuitive appeal and potential. The basic concept discussed would provide a student the opportunity to manipulate the terrain model in order to view it from different vantage points.. A variation of this theme involved using the contour map as a texture for the terrain model. This would be similar to the physical model discussed in Section II.E.2.a. However, such a computer-rendered model could easily provide egocentric views from any vantage point including ground level. An example of this is depicted in Figure 15. This could replace the conventional three-dimensional maps currently used in some training environments. It would have the added advantage of being able to provide an egocentric view. Properly implemented, the interface could allow the user to manipulate the model in a distant view until they found a point they were interested in seeing from an NOE altitude. Further manipulation could allow the user to transition to the NOE view from the appropriate position.

Figure 15. Example of an air navigation chart used as a texture on a terrain model.

E. POTENTIAL OPERATING MODES

Although this system under discussion was primarily focused on use by one individual for terrain navigation training, the media and interface could support related uses. The difference between some of these modes may be a change in name only.

1. Multi-Student Mode

One of the alternative uses discussed more accurately models how navigation is performed in the aircraft. As discussed in Section II.C.1, one individual would never be tasked with both navigating and controlling the aircraft. An interface that supports this notion of navigation as a crew concept could prove valuable. If the trainer were used in this mode by two students, they would have the opportunity to discuss the process of terrain association. It can be argued that students would both improve terrain association skills and practice the verbal protocol they will use in the aircraft. This would also provide students the opportunity to compare techniques and determine which are the most effective.

2. Instructor-Student Mode

This alternative provides an even closer approximation to the aircraft event than that described in the previous section. In this mode the student's primary responsibility would be to provide verbal direction to the flying pilot. The instructor could physically control the model as directed by the student. The instructor could monitor common errors and provide suggestions to improve performance. The trainer is much more conducive to effective debriefing than the aircraft. In the aircraft it is impractical to stop, manipulate the viewpoint, and discuss terrain features and their contour map representation. The trainer easily facilitates this and thus could dramatically reduce the training time required. Instructors could also assess student progress and determine if students required more simulation time or were ready for the aircraft events. This mode could easily be extended for classroom use. This basic tool could be used by a single instructor to present aspects of terrain navigation training to a class.

3. Refresher Training Mode

Many of the more experience helicopter pilots who have seen the system have expressed interest in its ability to provide refresher training. Terrain association and navigation is largely viewed as a perishable skill. To prepare for specific missions and to maintain skill level, some form of navigation experience is extremely helpful. Generally, some minimal amount of time is required to re-acquire previous skill levels. Performing this navigation in a simulated environment could extend proficiency gained in the air and speed re-acquisition of this skill when proficiency declines from lack of practice. The variety of types of terrain that could be modeled and included makes this tool very attractive in this role.

4. Mission Rehearsal Mode

Although excellent mission rehearsal tools exist, they are not generally well suited to the helicopter community and are not widely available. Judged an excellent fixed wing rehearsal tool, TOPSCENE does not provide the wide field of view that is vital to helicopter pilots. With improved accessibility and a wider field of view, TOPSCENE could prove to be an equally outstanding tool for the helicopter community. In lieu of an improved TOPSCENE, an extension of this tool may prove to be effective for helicopter missions.

IV. IMPLEMENTATION

A. HARDWARE AND PHYSICAL SETUP

The current system was developed to run on a Silicon Graphics Incorporated (SGI) Indigo2 with IMPACT Independent Channel Option (ICO). The hardware capabilities of this machine are listed in Table 3.

Parameter	*Value*
Machine Name	Kahuna
Machine Type	SGI Indigo2
# Processors	1
Processor Type	R4400 IP22
Processor Speed	200 MHz
Main Memory	128 Mbytes
Graphics Pipe	Maximum Impact with IMPACT Independent Channel Option

Table 3. Hardware description of current system.

1. Independent Channel Option (ICO) Functional Description

The ICO system allows from one to four monitors to be used for display. This system is depicted in Figure 16. The system supports two main video modes: normal and ICO. Changing video modes directs output from the frame buffer at the pixel bus (depicted in Figure 16 at the center of the IMPACT graphics subsystem.)

In normal mode, output from the frame buffer is rendered to the standard IMPACT monitor. Normal graphics mode behaves as a standard single video output configuration. When ICO mode is selected, output from the frame buffer is directed to the ICO subsystem in lieu of the primary IMPACT monitor. Within the ICO subsystem the original frame buffer is divided into four quadrants. Each of these quadrants is mapped via the crossbar switch and Digital to Analog Converter (DAC) to a video channel associated with one monitor. The resolution of the frame buffer is 1280 by 1024 pixels. Thus, the highest resolution possible in ICO mode is 640 by 480 pixels on each monitor or Video Graphics Array (VGA) resolution.

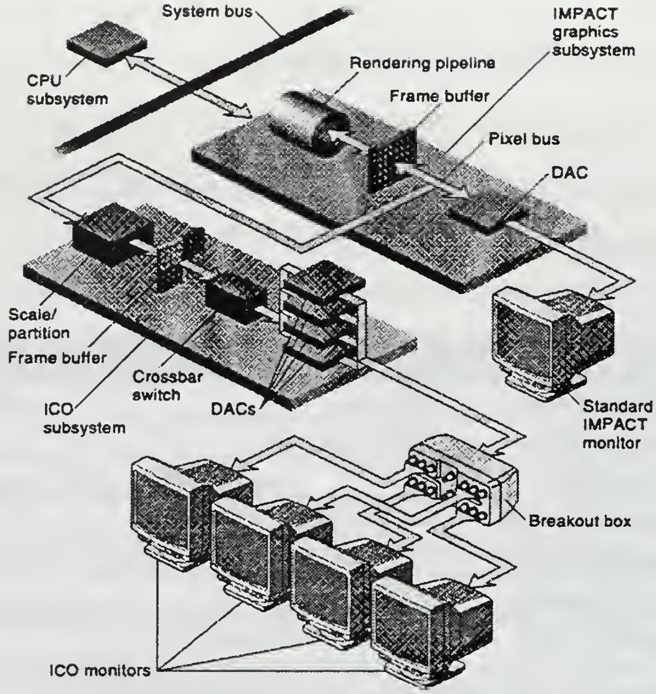

Figure 16. From (SGI, 1996). Basic independent channel option (ICO) schematic.

There are two methods to manipulate the video mode: from within a graphics application, or from the command line. Silicon Graphics (SGI, 1996) contains programming examples of how to query the hardware capabilities and video mode of the host machine. Also included in these examples is source code to manipulate the video mode. The current implementation does not incorporate this capability. It relies on the operator to invoke the program and reset the video mode in separate command line steps. Although these commands have been incorporated into a single script file, this is not a very robust scheme. A more robust system should exploit the capability to check and manipulate the video mode.

2. Display Setup

The current implementation used three Mitsubishi HL7965 19-inch monitors. These monitors have approximately 15 inches of viewing area and a resolution of 1280

by 1024 pixels. To create an egocentric fly-through application, the monitors were configured based on the connection and numbering sequence shown in Figure 17.

Since it was envisioned that the user would manipulate a control device to interact with the system while referencing a paper contour map, adequate space had to be left between the user and the monitor. After measuring a variety of subjects conducting the expected range of activity that might occur, it was determined that the distance of the average user to the monitor was approximately 29 inches. At this distance, each monitor occupies 27 degrees of the user's field of view and the obstructions created by the monitor casing obscure seven degrees of the user's field of view.

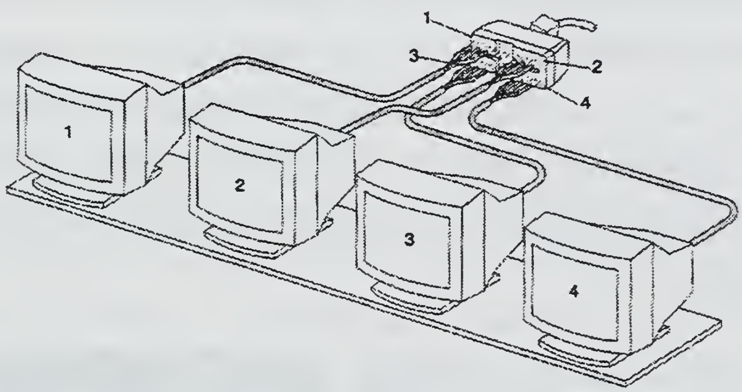

Figure 17. From (SGI, 1996). Monitor setup and numbering convention.

a. Four Monitor Configuration

Based on the geometry described above, a permutation of the original four-monitor configuration is shown in Figure 18. The user sat in the center of the display, facing forward. The original four-monitor display occupied a total field of view of 129 degrees. Monitors three and four displayed the view volume from straight ahead to 64.5 degrees right. Monitors one and two display from straight ahead to 64.5 degrees to the left. Despite the advantages of a four-monitor configuration, the three screen option proved to be more viable.

b. *Problems With a Four Monitor Configuration*

There are several problems associated with a four-monitor display system. These problems proved insurmountable in the current implementation. Ultimately the position of the monitor borders, the wide aggregate field of view, and anticipated problems porting to other platforms lead to the decision to use three monitors.

If an even number of monitors are used and the viewing frustum is aligned with the motion axis, the center of the user's field of view will be filled with the borders of monitors two and three. During initial trials, this proved to be very distracting. One solution investigated involved offsetting the viewing frustum. Trials were conducted with the viewing frustum offset 32 degrees to the right. With this off axis configuration, monitor number three represented the center windscreen of the aircraft; that is, it was aligned with the axis of forward motion. The total field of view rendered was still 129 degrees. The leftmost pixel rendered on monitor number one represented a point 89.5 degrees from the center of the aircraft. The rightmost pixel rendered on monitor four represented a point 49.5 degrees from the center of the aircraft. This configuration is shown in Figure 18.

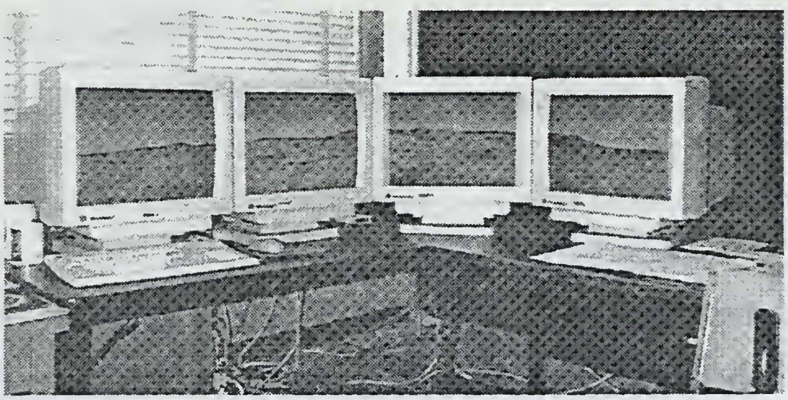

Figure 18. Four monitor off-axis configuration.

Although the configuration described above closely mirrors the task in the aircraft for Cat-I FRS students as described in Section II.C.1, recreating the aircraft was not the intent of this system. Since Cat-I FRS students fly terrain navigation syllabus events in the left seat, this configuration is a reasonable approximation of the task they are preparing for. It was not assumed however, that recreating the aircraft was the

optimal technique to improve student's terrain interpretation skills. The intent of this system was an optimal learning platform, not necessarily a tool to prepare for two syllabus events flown from the left seat. Additionally, adopting this configuration could limit the degree of usefulness for other platforms and communities.

To address the impact on universal applicability, a dynamically configurable display was considered. In this scheme, a system administrator or other super-user could manipulate the orientation of the viewing frustum. This would allow users to select the viewing orientation. A key binding was added which allowed the user to alter the offset of the viewing frustum and align the axis of motion with the monitor of their choice. Although this may be a useful feature for other and possible future implementations, this significantly complicates the interface and potentially the time it takes to learn to use the system. Since minimal time to learn the system is a primary goal, a configurable display option was not pursued further.

Lack of universal applicability was not the only problem with the off axis setup. During usability studies, users were confused by the monitor arrangement. They frequently had difficulty determining what the relative bearing of objects viewed on monitor number one would be. This problem seemed to be a result of the lack of symmetry of the display. The frame rate to render 129 degrees field of view was approximately 5 to 10 frames per second (fps). While this frame rate is marginally acceptable, it is at the threshold associated with real-time interactive control. Interactive control is viewed as essential. Marginal performance would quickly lead to frustration with extended use. Therefore, frame rate for the system should, at a minimum, maintain 10 fps. The frame rate associated with a three-monitor configuration was from 10 to 15 fps. Finally, future development on Windows NT hardware may allow a maximum of only three monitors. Since the ultimate goal of this project is to migrate to a Windows NT platform, it is not reasonable to measure a system that cannot be easily recreated on Windows NT.

c. *Setting Up a Three Monitor Display*

The three-monitor setup used for the experiment is shown in Figure 19. The center monitor represented the view directly in front of the simulated vehicle. The

right and left monitors represented views out left and right windows respectively. Based on the original geometry outlined above, the total field of view for this display mode is 95 degrees.

Figure 19. Experimental setup using three monitor display.

B. SOFTWARE

This application was created using the Performer and OpenGL Application Programmer Interfaces (API). The fly-through is extremely basic and relies heavily on fundamental concepts demonstrated in SGI's programming examples (SGI, 1996).

1. Programming Using ICO

Programming a fly-through application that exploits the multiple display capability of the ICO system is rather straightforward. The first step required is to determine what portion of the view volume to render on each monitor. If the monitors are set up following the number scheme shown in Figure 17 the most logical setup is to draw the right half of the view volume to monitors three and four and the left half to monitors one and two. With this configuration, the user would sit in the center of the

monitors and face the center of the display. The fly-through application would then correctly simulate egocentric motion.

After determining what to render on each monitor, the next step is to determine which quadrant of the frame buffer is mapped to each monitor. The frame buffer is mapped to the monitors according to the following scheme (SGI, 1996). The upper left quadrant is mapped to monitor one. The upper right quadrant is mapped to monitor two. The lower left quadrant is mapped to monitor three. The lower right quadrant is mapped to monitor four. Thus, the right view would be rendered to the top half of the frame buffer, and the left view would be rendered to the bottom half of the frame buffer.

Initially, this application was developed using the two-channel scheme described above. However, the gaps between the monitors created a problem. When a pixel left one monitor, it immediately appeared on the next. For a credible degree of realism, the monitor cases should have the same effect as the vertical supports for the windscreen in the aircraft. That is, as an object (pixel) passes from one section of the windscreen (monitor) to the next, it should momentarily disappear from view.

To model this behavior at the gaps between monitors two and three, one would have to simply offset the right view slightly to the right, and the left view slightly to the left. However, this does not solve the problem of the gaps between monitors one and two and monitors three and four. The only viable method to solve this problem is to use a separate rendering channel for each monitor. Thus, the current implementation uses 1 channel for each monitor.

2. Basic Motion

Chapter II discusses the rationale behind the decisions relating to control of the viewpoint. Table 1 summarizes the features of the ideal motion control interface. Developers considered a variety of input devices to incorporate the features listed in Table 1. These included a conventional mouse, three-dimensional spaceball, and joystick device. Because motion control involves inputs aligned with two perpendicular axes (forward and back, up and down), developers concluded that mapping conventional mouse inputs to these axes would involve a difficult learning process. Since this conflicts with the goal of an easy-to-learn system, control with a mouse was ruled out. Similarly,

since few users are familiar with three-dimensional spaceballs, this was not considered as an input device. Developers concluded that to decrease the time to learn how to use the system, a control device similar to aircraft controls should be used. The device selected was the FlyBox by BG Systems Incorporated. It is shown in Figure 20.

Figure 20. Input device for current implementation: the FlyBox from BG Systems Incorporated.

a. Speed Control

The updated viewpoint is calculated by evaluating the distance traveled. Distance traveled is computed based on speed and time. Speed is read directly off the interface device. Time is read off the system clock. On the FlyBox, the lever on the far left of the control box sets the speed. Lever position is mapped to speed according to the following linear interpolation: The full back position (towards the user) corresponds to maximum reverse speed. The neutral position corresponds to stop motion. The full forward position corresponds to maximum forward speed. Each frame, the time elapsed since the last frame is checked on the system clock. Distance traveled is computed as a

function of the speed set with the throttle and the elapsed time. This scheme ensures consistent speed throughout the simulation regardless of frame rate.

The mapping described above proved troublesome during usability studies. The linear interpolation of lever position to speed made it difficult to stop the helicopter model. Frequently, users wanted to stop to check the paper map. They would either set as close to zero forward speed as they could and hurry their map check, or call up the YAH map and intentionally ignore it. (Section IV.B.4 contains a complete description of the YAH map.) Users needed to ignore the YAH to attempt to resolve the paper map and the scene without assistance. To solve this problem, a null region was created about the center position of the lever. The center 10 percent of the lever's travel is mapped to zero forward speed. The remaining 90 percent of travel is mapped to forward and reverse speed as described above.

Maximum speed can be adjusted via key press. This feature was added primarily to facilitate usability studies. It allowed the evaluator to manipulate and evaluate the impact of different maximum speed settings. This feature was also extremely useful for developers to quickly survey terrain models. A similar feature may be desirable in a mission rehearsal mode of the current system. A more flexible and robust means of adjusting the range of speeds may marginally improve the current training system, and would increase the scope of applicability of this system. During usability studies, evaluators noted a tendency of users to set the maximum speed. Typical maximum speeds for helicopters are from 120 to 150 knots. This is well above the normal terrain flight airspeeds, and not at all conducive to training. The maximum speed in the implementation tested was 95 knots.

b. Heading Control

For egocentric motion, heading is adjusted by lateral displacement of the cyclic stick. To turn, the user displaces the cyclic in the desired direction. The model heading is then incremented or decremented as appropriate. As with the other controls, stick inputs are mapped to change in heading using a straightforward linear interpolation. During development, a key binding was incorporated to allow the developer to adjust the maximum turn rate. This feature was incorporated to evaluate the effect of turn rate on

user satisfaction. This allowed the developers to determine a reasonable setting. The turn rate in the implementation tested was approximately 60 degrees per minute.

c. Altitude Control

Altitude is controlled with longitudinal cyclic displacement. Pushing the cyclic forward decreases the AGL altitude; pulling back on the cyclic increases the AGL altitude. As with speed and heading control, the magnitude of change in altitude is derived from a linear interpolation of stick displacement. The maximum climb rate used in the implementation tested is approximately 8000 feet per minute. This is well above the normal capability of helicopters of approximately 1500 feet per minute.

3. Exocentric Viewpoint

The exocentric viewpoint was added to provide an alternative means to view the terrain model. Section III.D discusses in detail the motivation and guidelines for adding this feature. The basic principle followed was that the exocentric view should be easy to access, should stop vehicle motion, and the transition from ego to exocentric views should be continuous. Two views of the exocentric view are provided in Figure 21 and Figure 23.

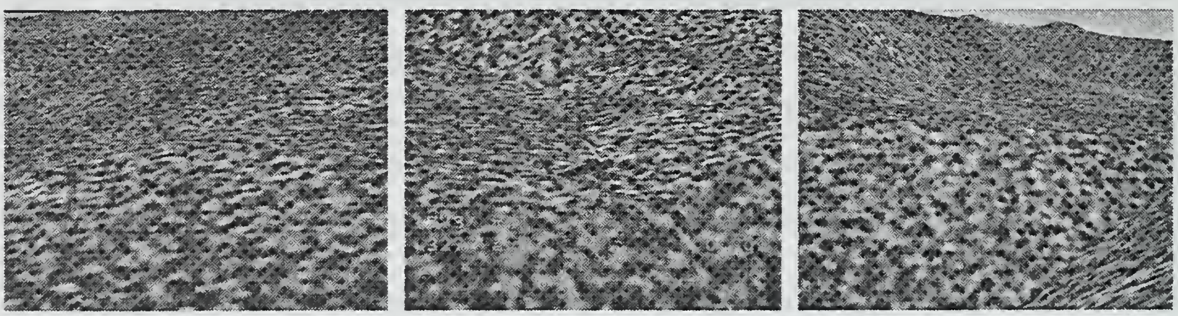

Figure 21. Short range exocentric view.

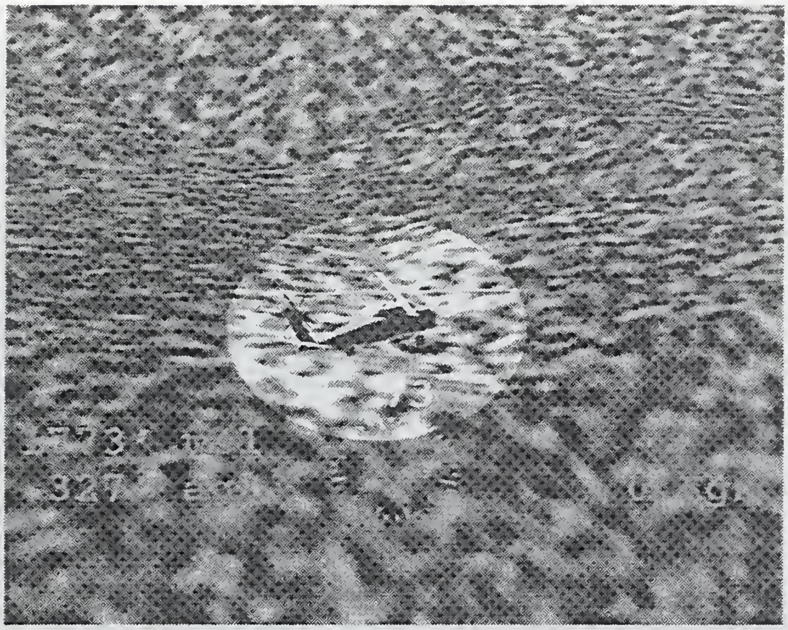

Figure 22. Image from center screen from Figure 21 with helicopter highlighted.

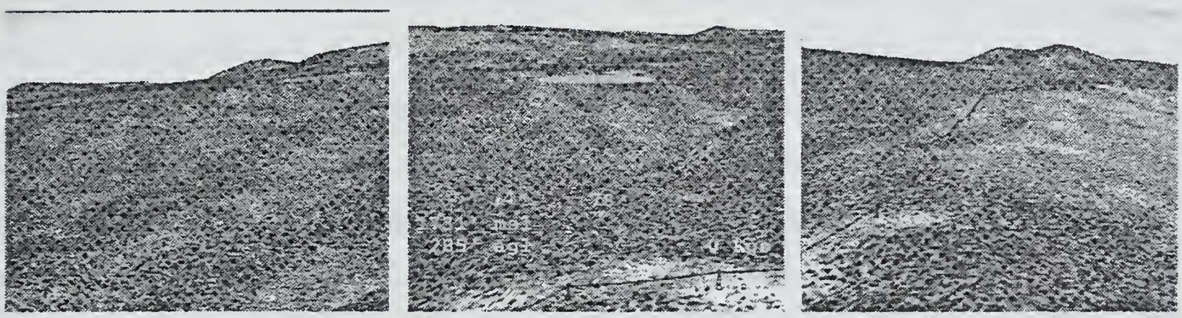

Figure 23. Medium range exocentric view.

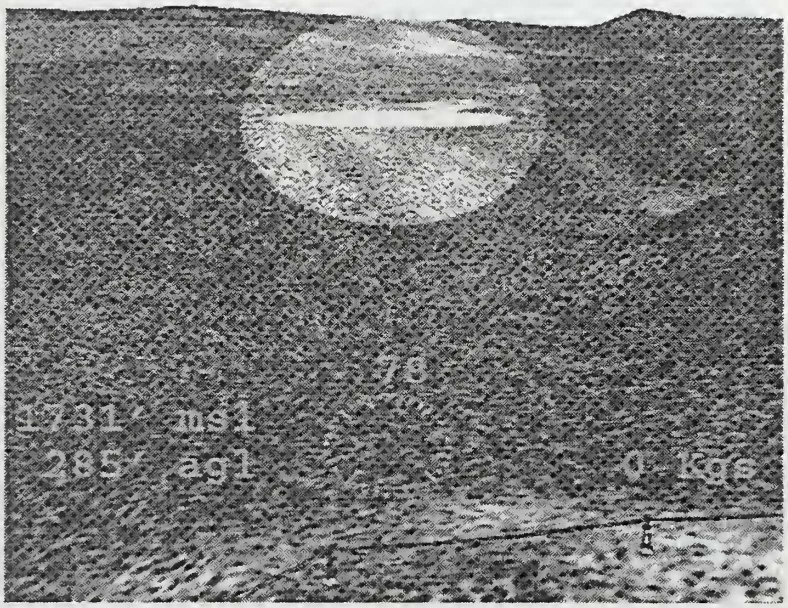

Figure 24. Image from center screen from Figure 23 with icon representing helicopter's position highlighted.

a. Functional Description

Pressing and holding the trigger switch on the cyclic stick accesses the exocentric view. When the switch is depressed, the viewpoint is detached from the vehicle. The user controls the viewpoint by pulling the cyclic stick back (towards the user). This moves the viewpoint away from the model. Pushing the cyclic stick forward moves the viewpoint closer to the helicopter model. Pushing the cyclic stick right moves the camera counterclockwise around the helicopter model. Pushing the cyclic stick left moves the viewpoint clockwise around the helicopter model.

The viewpoint remains on a fixed 10-degree glide path. During the development process, several alternative methods to control this angle were explored. After testing various methods, it was determined that incorporating control of the view angle would make the learning curve too steep. The viewpoint remains centered on the helicopter model. When the viewpoint is 5000 meters from the helicopter, an icon appears above the helicopter model. The icon is displaced above the model to minimize the chance of the icon and terrain images interfering with each other.

When the user releases the trigger switch, the viewpoint automatically rejoins the helicopter model. If the trigger switch is not pressed and the viewpoint is not in position, the viewpoint first aligns with the heading of the helicopter. If the viewpoint was moved straight back and to the right of the helicopter (counterclockwise), the viewpoint would move left until it was directly behind the helicopter model and facing the same direction. Once the viewpoint is aligned with the helicopter, it moves toward the helicopter along the same 10-degree glide path it flew out on until it rejoins the egocentric view.

b. Programming Considerations

As mentioned above, distance from the viewpoint to the helicopter is controlled by longitudinal displacement of the cyclic. A 'distance' variable is incremented and decremented based on stick position. Viewpoint motion is a function of the square of this distance variable. This way, as distance from the helicopter model to the viewpoint increases, rate of motion increases appropriately. Motion around the model is controlled by lateral displacement of the cyclic. Lateral displacement of the cyclic increments and decrements a variable for angular displacement. This technique ensures that lateral motion happens at an appropriate rate regardless of the distance from the viewpoint to the model.

The code for the viewpoint to realign with the egocentric perspective works with the variables described above. Based on the current position, the variables are incremented or decremented as appropriate. Using the same variables ensures that motion will be a consistent throughout transitions to and from ego and exocentric views. When the viewpoint is animated back to the egocentric perspective, maximum rates are used. These rates correspond to full cyclic displacement.

4. You Are Here (YAH) Map

a. Creating the You Are Here (YAH) Map

The digital map image was created using Coryphaeus Easy Terrain, captured using SGI's SnapShot tool, converted with SGI's ImageView tool, and

manipulated with Adobe PhotoShop. The intent was to create a two dimensional texture map. This image could be used as a texture for a terrain model or as a bitmap for an electronic map. Section II.B.2 discusses the motivation for providing a YAH map. This section discusses the steps to produce this map. Two views of the map are shown in Figure 25 and Figure 26.

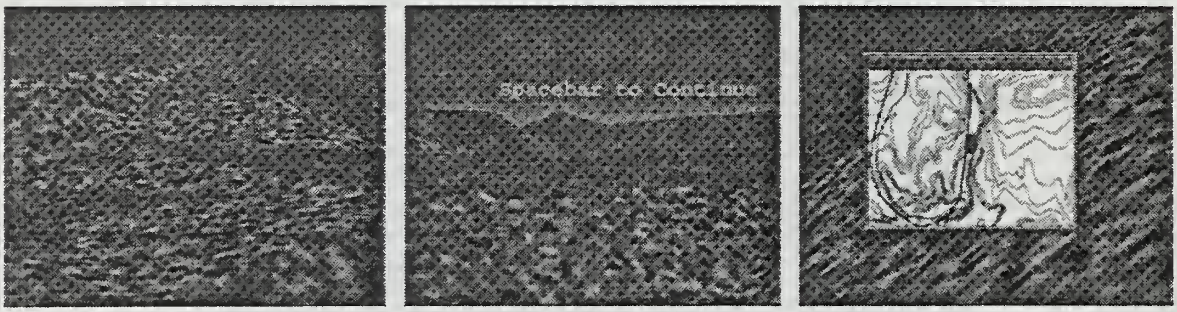

Figure 25. Three-screen display with YAH map invoked.

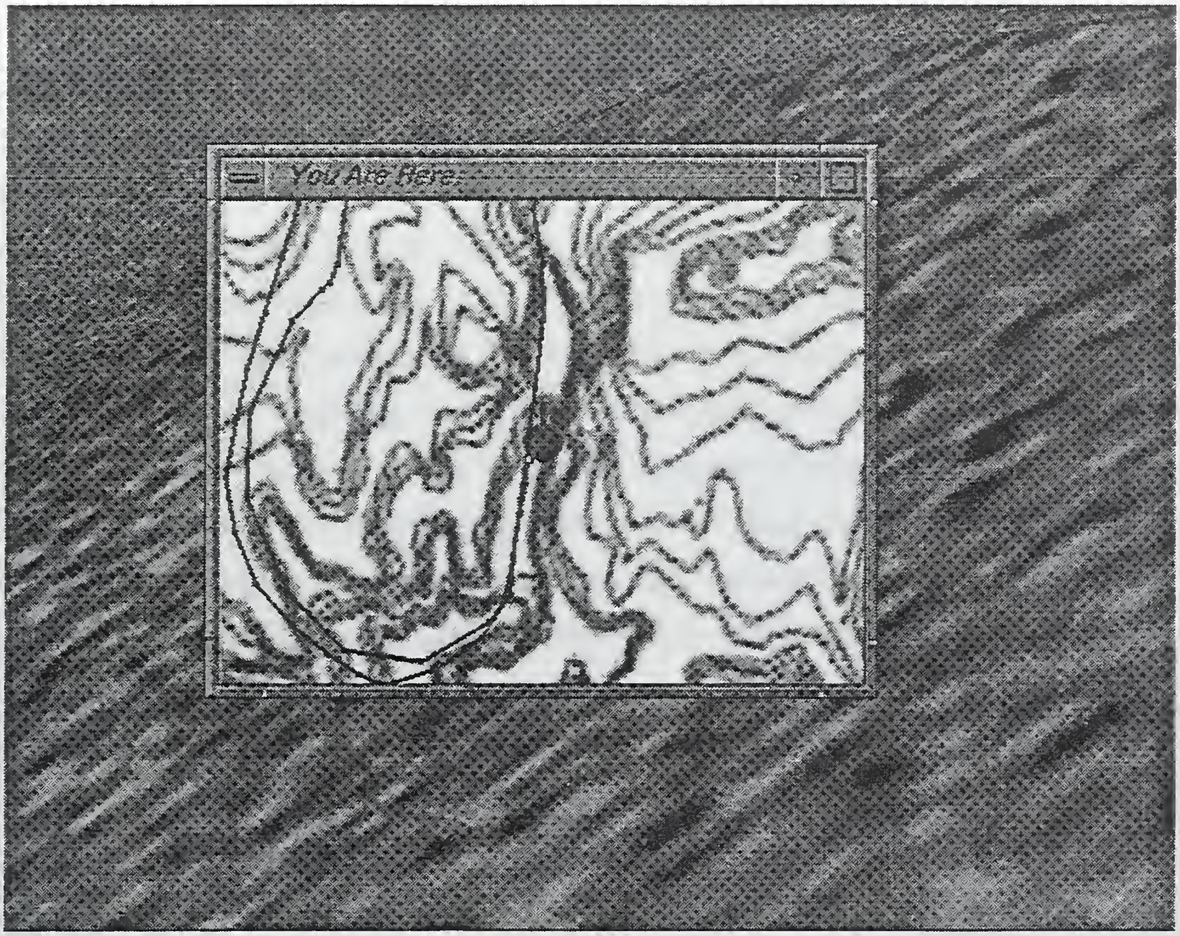

Figure 26. YAH map display.

In Easy Terrain, the contour interval is adjusted by selecting the number of bands displayed on the elevation chart. To estimate the number of levels required to approximate the contour interval, first find the minimum and maximum elevations of the area to be mapped. Minimum and maximum elevations for bounded regions are displayed using the coordinate information window. Dividing the difference between the maximum and minimum altitudes by the desired contour interval yields a good estimate of the number of levels required. Selecting 'View' and 'Contour Interval' displays the resulting contour map.

Capturing this screen image to create a texture file was done with the 'SnapShot' tool. The area modeled was too large to display and capture as one image. Therefore, the digital map had to be created by quadrants. To make it easy to later reconstruct a single image, each sub-image covered an equal geographic area, and was

captured in a uniform dimension image. The proportions of the area used for screen capture matched the proportions of the quadrants of the model. Each quadrant was selected using the 'Pick' and 'By Latitude/Longitude' options. This ensured each quadrant would be exactly the same size. After a quadrant was selected, the view was adjusted by selecting the 'View' and 'Fit' option. The view was then adjusted by selecting the 'View' and 'Initialize Trackball' option. These steps ensured the selected region was centered and normal to the viewpoint. The area bounded for screen capture was not changed and this sequence was repeated for each quadrant.

The product of the screen capture is a classic SGI (.rgb) formatted file. To facilitate combining the images into a single file, the original screen capture files were converted from classic SGI mode to the more universally recognized JPEG format with the ImageView tool. The JPEG images were then combined into a single texture using PhotoShop. A single image of the required size was created. Each quadrant was then imported into a new layer. The 'offset filter' was used on each these layers to correctly position the sub-images. Finally, the image was flattened and saved as a JPEG. The ImageView tool was used to convert this image back to the classic SGI format for use as a texture.

b. Programming the YAH Map

As described in the previous paragraph, the map used in this application was a two-dimensional texture in classic SGI format. Thus, the moving map could be implemented directly as a bitmap display, or it could be used as a texture on a terrain model. Using the texture as a bitmap would improve performance. Using the image as a texture on a terrain model would allow the user to access alternative views of the mode. (This concept is discussed in Section VII.B.4). This later scheme was implemented during program development. Although the current implementation does not exploit the three-dimensional characteristics of the model, it was not reprogrammed using a bitmap.

For an earlier implementation, the YAH map needed three-dimensional characteristics. When invoked, the YAH map came up as a conventional map display. The map was rotated to align with the helicopter model. The viewpoint was directly above the model and was oriented straight down. In this implementation, the user could

then manipulate this model to aid visualization of the contour lines. The interface to this system proved to be too cumbersome, and this approach was abandoned. The current implementation relies on the same model, but does not require three-dimensional characteristics. Changing to a bitmap could substantially improve performance.

Two schemes were investigated for implementing the YAH map. The first scheme used a separate channel drawn in a fixed position on monitor four. The second scheme opened a new window over a portion of the display. The channel technique does not involve context switching, and therefore had much better frame rate performance. Although frame rate performance was worse, programming sizing and positioning of the YAH map was much simpler using a separate window. Since vehicle motion is stopped when the YAH map is referenced, frame rate performance was not viewed as significant. Additionally, the ability to move and resize the window facilitates cross-checking the contour map and the forward view. If the map obscures the feature the user is trying to disambiguate, the user can reposition, resize or iconify the map. Thus, the current implementation uses a separate window to render the YAH map.

The YAH map is toggled off and on by pressing the spacebar. When the YAH map is in view, model motion is frozen and the text 'Spacebar to Continue' is displayed on the center monitor. The user can control the zoom factor on the map with the second lever from the left on the FlyBox. Pushing the lever forward moves the viewer closer to the map. Pulling the lever back toward the user moves the viewpoint away from the map. The minimum distance of the viewpoint from the map is 8000 meters. The maximum distance of the viewpoint from the map is 38000 meters.

5. Head Up Display (HUD)

The HUD (shown in) is extremely rudimentary. It is designed to provide the minimal information needed to navigate without distracting the user from the primary task. The HUD was originally developed in Coryphaeus' Designer's Workbench (DWB). The DWB model could not be imported directly because of problems updating the appropriate simulation variables (such as ground speed). Several other avenues were explored to use the HUD created in DWB.

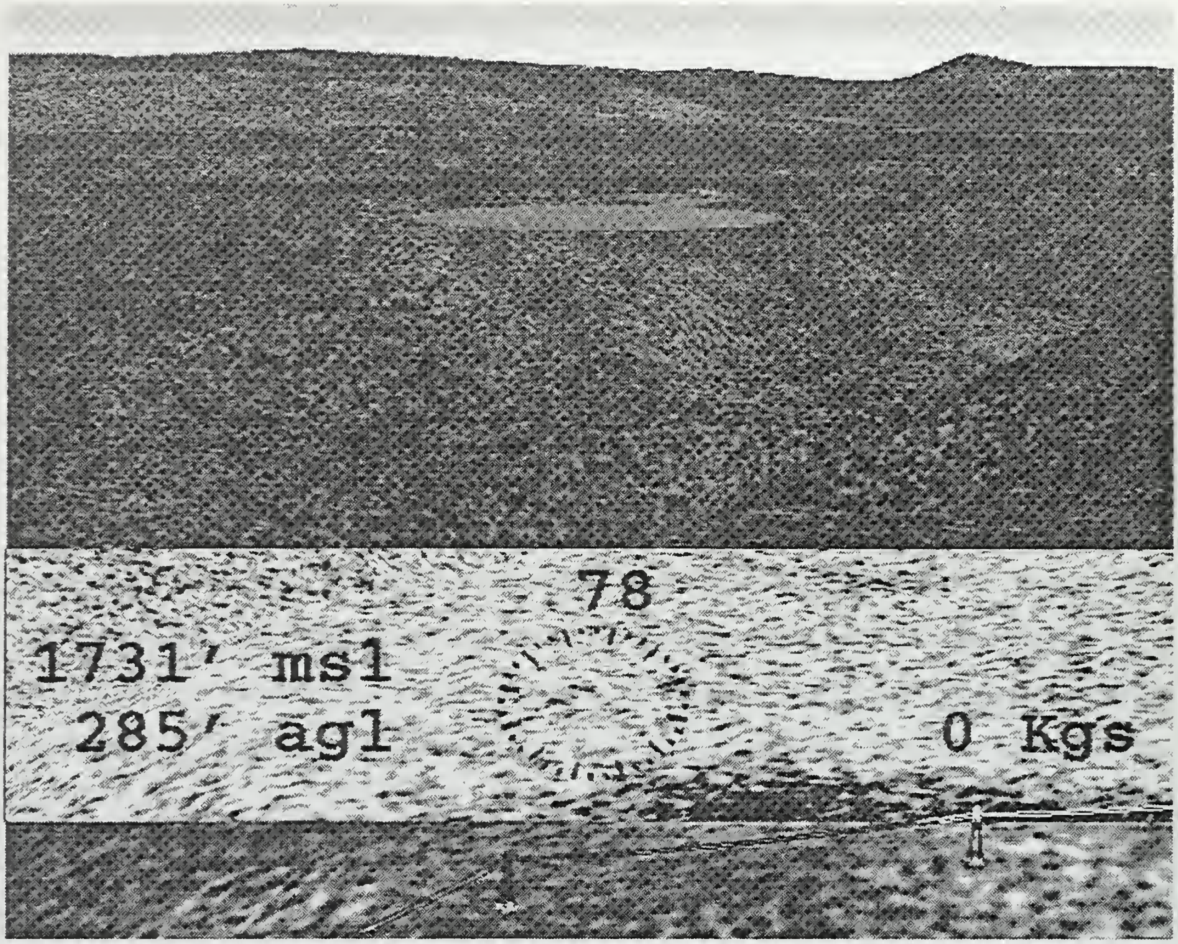

Figure 27. Exocentric view with the HUD region highlighted.

Designer's Workbench exports 'C' code. Unfortunately, it exports IRISGL code. This code is incompatible with the OpenGL code that had already been created for the simulation. An attempt was made to use an IRISGL to OpenGL conversion program. Although this idea showed early promise, in practice it was not feasible. The final HUD implementation relied minimally on Designer's Workbench. The only feature used from the original HUD was the compass card. The HUD was exported as 'C' code. The data structure from which the compass rose is drawn is an array of sets of three floating-point numbers. These numbers represent the three-dimensional coordinates of the endpoints of the radial lines on the compass card. This array was used as input to the OpenGL 'DrawLine' function. The remainder of the HUD is text based. It was programmed using Performer text drawing facilities.

6. Other Feedback Mechanisms and Controls

Based on the feedback requirements outlined in Chapter I, a mechanism for creating and depicting training routes and displaying the user's track was included. Both of these mechanisms are displayed exclusively on the YAH map. The user controls these features either with the GUI or via key press. Both tools rely on the rudimentary record feature.

Every five seconds, the helicopter model position and heading are written to a new data file. When the user calls up the YAH map, this data is used to recreate the user's path through the terrain model. The position information is used to create a geometric structure within the model. In an early implementation, the user's track was displayed both as an overlay on the YAH map and as a three-dimensional path over the terrain model. The three-dimensional display was removed from the terrain model because it could actually interfere with terrain interpretation training. Since the user has access to an exocentric view and a paper copy of the map with the training route depicted, the user could simply try to make his path look like the path drawn on the paper map. Although the current implementation does not exploit the three-dimensional characteristics of the path, this characteristic was maintained to support future development.

The training routes are created from the data files described above. On program initialization and when the user opts to change the training route, a training route data file is opened. These files are named to correspond with the color coded routes they depict (e.g. blue.dat). To create a new route, the evaluators flew the route and renamed the newly created data file with the appropriate file name. Following this script, it is relatively simple to alter training routes.

Users have very few options to manipulate the display of the tracks. If users have covered the same territory several times and their path is no longer depicted clearly, they can erase the track. This is accessed via the GUI (described in the following section), or with the DELETE key. If users become disoriented since the last time they brought up the YAH map, they can go back to the point where they last brought up the YAH map. This is accessed on the GUI or with the BACKSPACE key. Several features are

available only with the GUI. The user can select a new training route with a menu bar. The available options are: Red, Blue, Black, None, and All.

7. Graphical User Interface (GUI)

The GUI was originally created for the developers to evaluate the impact of the variables that control the detail texture. The code was imported from SGI (1996). Controls corresponding to the feedback mechanisms listed in Section IV.B.6 were added. Additional functionality was added, again primarily for the developers. Usability studies were not conducted on the GUI. For the experiment, the evaluator acted as a mediator. The users were briefed on the features available. The evaluators performed any functions accessed through the GUI. The GUI in the current implementation was not designed to be easy to learn or use. It was designed exclusively for the developers. The GUI is not normally in view. It is toggled on and off via key press (F1).

Button Label	*Button Type*	*Action(s)*
Reset All	Radio	Reposition helicopter to beginning of default route. Clear student track. Set default fog, interface mode, statistics display
Go Back	Radio	Reposition helicopter to the last point a map check was conducted.
Change Route	Menu	Reposition the helicopter to the beginning of the selected training route. Clear student track.
Stats	Radio	Toggle statistics On/Off
Mode	Radio	Alternate between two interface modes
Fog	Radio	Toggle Fog On/Off
Near Fog	Slider	Adjust the near fog range
Far Fog	Slider	Adjust the far fog range
Quit	Radio	Quit application

Table 4. Grapical user interface (GUI) functionality.

V. METHODS

A single, overriding factor impacted both the experimental setup and data collection: this system was specifically designed and tailored to fit into an existing training program with minimal impact on the instructors and students. The major disadvantage of such an experiment is the lack of quantitative data, small sample size, and resultant lack of statistical impact. The major advantage, however, is that the qualitative data provides the information needed to judge overall efficacy of VE training, useful guidelines for any future adaptation of the system, and moreover, eliminates any concerns related to later transfer to the real-world task.

A. EXPERIMENTAL SETUP

1. Subject Pool

This experiment used eight Category One (Cat I) FRPs at HS-10. All subjects were males between the ages of 22 and 25. Category One students were selected because they have approximately equal helicopter terrain navigation experience. Having recently completed the undergraduate flight school pipeline, Cat I students have nearly identical flight experience. Each has completed approximately 220 flight hours including three 2.5-hour terrain navigation training flights during the advanced phase of the undergraduate pipeline. These flights are conducted at Naval Air Station Pensacola Florida where the terrain is uniformly flat and nearly featureless. Primary cues for navigation in this area are cultural features and the difference in vegetation associated with waterways. It is difficult to find another group with similarly matched experience levels, and difficult to determine the level of experience and ability of more experienced pilots. Unfortunately, the subject pool is very limited. The Warhawks of HS-10 train approximately 45 Cat I students annually.

2. Treatment

To accommodate data collection, the system was tested in a manner inconsistent with one of the major design principles. Although the ideal system would be available

for unlimited use at the discretion of the students, making such a system available and measuring the impact it had on training was not feasible. Since the interface could not be fully tested with usability studies (this is discussed more completely in Section VII.A.2.), the initial round of data collection served as validation of the interface. Obviously, this required experimenters to be available during the initial trials. Consequently, a system that provided unlimited, asynchronous access could not be tested.

The treatment was further impacted because it was designed not to interfere with the existing training pipeline. Students normally conduct terrain navigation training in conjunction with a three day CSAR ground school. Ground school is scheduled to accommodate NVG training flights. These flights require favorable moon light conditions (nearly full moon, and high moon angle). To maintain currency, minimal time should elapse between ground school, day terrain navigation flights, and NVG flights. In combination with the requirement of experimenters to be on site during system use and to ensure each student received equal training, VE training was scheduled as part of the CSAR ground school and restricted to one hour of training for each student.

Each student's hour of training involved approximately 15 minutes of instruction, and 45 minutes of VE training. During the instruction period, students were presented the paper copy of the 1:50,000 contour map with the training route and hazard depicted on it. Experimenters briefed the students on the features of the system (how to control vehicle motion, the feedback and control features available). Experimenters requested that students provide a verbal protocol by "thinking out loud". Specifically, they were asked to keep the experimenters informed of what features they were looking at on both the contour map and the cockpit views and how confident they were of their navigation solution. Students were also informed that experimenters may ask questions during the session, but their priority was to maintain navigational frame of reference, and that they should stop vehicle motion if necessary. Students were informed that experimenters were interested in how this system would be used by pilots if it were available in the squadron. They were told that their performance during the training session would not be recorded for their training records, and that only the experimenters would have access to any information collected. Experimenters were available to answer questions on any system features. All student sessions were tape-recorded. Students were debriefed after the

training session, and after the training flights. Similarly, IPs were debriefed after training flights.

B. DATA COLLECTION

Navy doctrine prohibits passengers on training flights. Pilots at NPS are not in a flight status, are not considered aircrew, and thus, are not allowed on training flights. Subsequently, all in-flight analysis was performed by HS-10 IPs. Although the aircraft are equipped with GPS, post-flight access to this information is severely restricted. Additionally, without in-depth analysis of *why* an aircraft was off track, GPS data itself is marginally useful. For example, if a student intentionally maintains position near but off track to keep a channeling features in sight he is, in fact, exhibiting sound navigation procedures. Raw GPS data could easily obscure this fact. Correlating GPS data and student performance with IPs would be labor intensive and thus impact the training sequence. Instructor pilots are adept at determining a student's level of skill and knowledge. Therefore, in lieu of precise positional data, this experiment relied heavily on IP feedback on student performance. To minimize the chance that individual differences in IP grading criteria would skew the data, specific criteria were provided. Augmented grade cards are in Appendix A.

The taped transcripts, experimenter analysis of student performance, and the automated data collection output feature described in Section IV.B.6 provided data for analysis of student's use of the VE training system. The automated output was later used as input to create a graphical depiction of the student's training sessions. These can be found in Appendix B.

VI. RESULTS

The complications of measuring a real-world task outlined in Chapter V severely limit the amount of quantitative data available for analysis. Although the supplemental grade cards provide useful information, the relatively small sample size and lack of a control group make it difficult to draw conclusions based solely on this information. However, since this project was primarily intended to prove the concepts and assumptions of Chapter III, the qualitative data is more useful; it lends insight into what makes the system effective and areas that need improvement. Consequently, the results presented in this section are primarily based on anecdotal information: the subjective analysis by evaluators of student's VE training experience, interviews with students after they used the trainer and again after they completed the terrain navigation flights, and interviews with their instructor pilots.

A. SUCCESSFUL NAVIGATION IN VIRTUAL CAMP PENDLETON

At the outset, it was not assumed that subjects would be able to rely on terrain association skills to successfully navigate within the VE. Usability studies addressed, but could not resolve this issue; primarily because subject pools at NPS are dissimilar from the ultimate user group (Cat I FRPs). Subjects tested at NPS were divided into two groups; experienced helicopter pilots, and non-aviators. Helicopter pilots were useful because they are familiar with helicopter flight control systems and presumably have the same expectations and roughly the same level of ability controlling a simple fly-through. However, pilots tested during the usability studies had an average of 1500 hours of flight time. All rated their terrain navigation ability at or near the "expert" (highest) level. Obviously, this is radically different from Cat I students; they have an average of approximately 200 hours, and little terrain navigation experience. Non-aviators were useful subjects because they had roughly the same level of terrain navigation experience as Cat I FRPs. They, however, were not always familiar with flight control systems and lacked general aviation background and experience. These issues were evident during the usability studies and limited the degree to which successful VE navigation by Cat I FRPs could be accurately predicted.

Although several helicopter pilots familiar with the Camp Pendleton area could recognize terrain features in the VE and were comfortable navigating, they were doing so from memory and were not relying on the paper map, exocentric view, or YAH map. While it was encouraging that subject matter experts found enough similarities between Camp Pendleton and the VE representation to navigate, this was not the goal of the system. The system was intended for novice users, unfamiliar with the area, who would rely primarily on *terrain association*, rather than memory, to navigate. Pilots not familiar with the Camp Pendleton area did not provide a clear indication of the degree of difficulty the proposed task would present for Cat I FRPs. While it is assumed that a novice would rely heavily on feedback, one experienced helicopter pilot completed the route successfully without referencing the feedback mechanisms at all. This level of performance was not unique to one individual; all of the helicopter pilot subjects completed the task with minimal reference to feedback mechanisms. Clearly, this was not strictly a training evolution for experienced helicopter pilots, and thus lends little useful information about the quality of feedback provided.

Because non-aviators provided a closer approximation to a Cat I FRP's terrain navigation skill level, their demonstrated ability to navigate within the VE was more encouraging, but was not considered conclusive evidence that Cat I FRPs would be able to navigate in the VE. More importantly, these subjects could not provide useful information on *how* to improve the system for the intended user group. Because non-aviators did not have the same background knowledge, changing the interface to make it easier for non-aviators may not be appropriate. In some cases, non-aviators' lack of familiarity with the information displayed on the HUD interfered with the VE experience. Several of the non-aviators did not use the HUD at all. Consequently, they had considerable difficulty judging essential information for terrain navigation; how far they had turned, their height above ground, and their speed over the ground. While experienced helicopter pilots did not experience these difficulties, their skill level may have allowed them to complete the task without relying on the information presented on the HUD. Therefore, evaluators could not determine if the feedback was appropriate. The initial usability studies provided useful information, but did not provide conclusive evidence or clear direction for improvement.

Trials with HS-10 Cat I FRPs provided convincing evidence that novices could rely on terrain association skills to navigate in the virtual model of Camp Pendleton. For each of the eight subjects, their verbal protocol clearly indicated that they were relying primarily on terrain association skills to navigate. During low workload periods, students were asked "What are you looking at?" and "Where are you going?". Invariably, students' responses were based on terrain features. Typical responses were "I'm following this canyon looking for a draw on my left." and "I should see two saddles, I want to go to the one on the left.". Although initially most users relied heavily on the feedback mechanisms, they seemed to use the feedback as intended: a means to cross check their terrain association navigation. In particular, when subjects accessed feedback, their verbal protocol indicated they were trying to distinguish between ambiguous features. For example, one subject accessed the exocentric view near what he perceived as an ambiguous checkpoint. By viewing the feature (a peak) from various vantage points and continually comparing this feature to its map representation, he was able to satisfy himself that he was, in fact, on course. This was typical of all eight subjects, and provided clear evidence that subjects were navigating by comparing depicted terrain features and their contour map representations.

It is important to note that, particularly when subjects first started to use the system, they would access feedback frequently. Their verbal protocol data indicated this was primarily to increase their confidence in their navigation solution. As subjects progressed, over-reliance on the feedback mechanisms seemed to be less of a problem than reluctance to access feedback at all. Subjects seemed to demonstrate a natural aversion to relying on any form of feedback. They apparently assumed the challenge was to progress as far as possible without accessing feedback. This was the case despite the fact that the brief was designed specifically to avoid any negative connotations associated with accessing feedback.

B. IMPROVED TERRAIN ASSOCIATION NAVIGATION SKILLS

Based on subjects' verbal protocol data, to some degree, all demonstrated improved navigation in the VE. Initially, skill level as demonstrated by the strength and salience of the subjects' comments, varied widely. However, regardless of initial skill

level, all subjects demonstrated improved ability to relate terrain features and their contour map representations. One subject in particular improved dramatically in the 45-minute exposure. His initial comments were infrequent and unsure: "Um, I think I should be seeing a draw soon.". After struggling with resolution of several key features, the subject rapidly gained confidence and skill. Comments towards the end of the session included "I'm following this draw (indicating correctly). As it curves to the right I should see two small peaks at my two o'clock. I want to turn before I get to the second peak.". It is particularly interesting to note that apparently not only the subject's terrain association skills improved, but also, the protocol indicates application of sound navigation procedures. The draw mentioned above was being used as a channeling feature; and the two distinctive peaks were being used as checking features. While not all subjects' progress was as dramatic, all seemed to improve in their ability to resolve terrain features and contour map representations. Figure 28 and Figure 29 depict analysis for a typical session. Graphical depiction of each subject's session can be found in Appendix B.

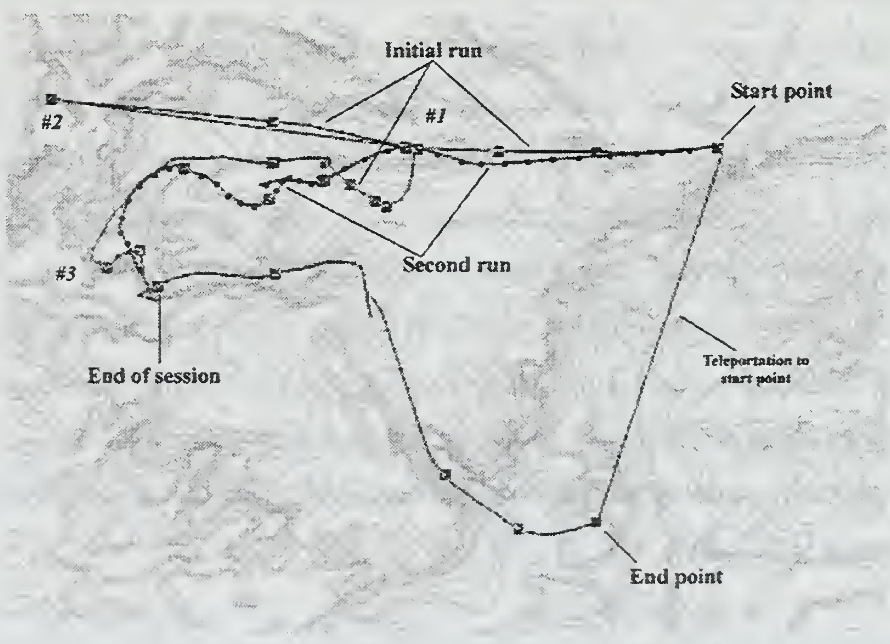

Figure 28. Example of graphic depiction of training session with evaluator's comments. (Boxes indicate reference to feedback -- YAH map or exocentric view. Figure 29 provides amplifying information.)

Evaluator Notes: Subject 2

On the initial run, the subject had difficulty at point #1. During the first leg (from the start point toward point #1), the subject maintained a slight offset north of track and failed to recognize the draw on the left that he should have followed. At point #2, the subject noted that he had crossed through a canyon. He recognized this as inconsistent with the goal, referenced the YAH map, and elected to teleport back to the last map-check location (as indicated by the straight line connecting point #2 to point #1). The subject had further difficulty regaining track and accessed feedback mechanisms several times (as indicated on the south-bound leg from point #1). Once the subject regained track, he identified and followed the correct draw with one map check. At point #3, the subject noted his heading (060 degrees) was not consistent with the orientation of the correct canyon (090 degrees). The subject used the exocentric view to determine his location. He identified a ridge on his right (southeast) and correctly associated this ridge with the contour map representation. He used this ridge as a channeling feature to regain track. From this point on, student accessed feedback much less frequently. The right turn (to southerly heading) after point #3 was made without reference to feedback. The student made a final map check prior to the end point to allow time to answer evaluator questions. Rather than change the speed with the throttle, the subject elected to stop motion by invoking the YAH map. The straight line from the end point to the start point indicates the subject elected to teleport back to the start point to retry the same route (vice reversing heading and executing the route in the opposite direction).

The subject's performance on the second run (track indicated with dots) indicates the subject relied much less on feedback mechanisms. The subject access the YAH map one time, backed up one time, and used the exocentric view two times prior to point #3. This is compared to accessing the exocentric view three times and the YAH map eight times prior to reaching point #3 on the initial leg.

Figure 29. Example evaluator notes associated with graphical depiction of training session depicted in Figure 28.

C. IMPROVED PERFORMANCE DURING TRAINING FLIGHTS

The majority of students (seven of eight) who received VE training performed better than the squadron average on terrain navigation flights. The average scores of those who received training was also above average. While this is a relatively small group from which to draw conclusions, post-flight commentary of both IPs and FRPs suggest that improved performance can be attributed directly to VE training. It is also

important to note that HS-10 trains approximately 95 Cat I FRPs annually. This study sampled roughly eight percent of the population.

The comments of one IP in particular strongly indicate that some students may have gained appreciably from the VE training. During the flight, the IP did not know that the FRP had received augmented training. During normal pre-flight briefing, the IP noted below average map preparation. Preparation is obviously critical for successful training flights, thus it is not uncommon for inadequate preparation to lead to difficulty (and possibly failure) during the flight. To the surprise of the IP, the FRP's performance, and in particular navigation ability, was excellent. In the view of the IP, excellent to the point of annoying (because of the lack of preparation). The IP commented that although he expected the student to perform poorly, he remained confident and easily handled extensive quizzing. The IP assumed that the FRP might have been relying on prior navigation experience. This was in fact not the case; the FRP had previously indicated that he had no prior contour map reading or navigation experience. While it is certainly true that this FRP's performance could be attributed to a wide variety of other factors (such as natural ability), based on post-flight interviews with the FRP, it seems apparent that the VE training contributed to his performance in the aircraft.

D. HIGH CONFIDENCE RATINGS, BOTH INSTRUCTORS & STUDENTS

Both instructors and students were favorably impressed with the basic system. All eight students tested responded positively when they were asked if they would use the system if it were available as a squadron training asset, and all eight indicated that it was a helpful tool. Their responses not only indicate that the fundamental goals of the system outlined in Section III.A are effective, they also support the concept of implementation described in Section III.A.5. That is, the system should be available for asynchronous, unlimited access, and training events should not necessarily be scheduled. Students responded favorably to the concept of unscheduled, unlimited access. From their comments, it was apparent that if such a system were fielded, it would certainly be well used. In fact, one of the students, concerned that his terrain flight might be delayed, wanted to know how he could gain access to the system again prior to his flight.

Instructors and the HS chain of command were also favorably impressed with the potential of the system. In particular, Cdr. Linnell, the Commanding Officer of HS-10, commented that such a system could save valuable flight time for maneuvers that could only be learned in the aircraft. Cdr. Linnell, as the primary individual responsible for the quality of FRPs assigned to Fleet Squadrons, has favorably endorsed funding such a system (Linnell, 1998).

VII. CONCLUSIONS

A. PROOF OF CONCEPT

The original intent of this work was to determine if it was possible to improve terrain navigation training by incorporating a VE system into existing training and to measure performance on a real-world task. Chapter III outlines some of the major assumptions made in the creation and implementation of the prototype system. This section describes the validity of the assumptions as demonstrated by improved performance indicated in Chapter III.

1. Part-task Training of Terrain Association Skills is Effective

Based on the discussion in Section II.A, the most appropriate components for part-task training can be easily separated from the whole task, do not share critical interactions with other tasks, and can be automated. Successful part-task training is indicated by improved whole-task performance. Because students who received training outperformed students who received no training, it is reasonable to assume that terrain association is an appropriate task to train separately. Improved performance also indicates that the overall training method (a wide field of view interactive fly-through with supernatural capabilities and rudimentary feedback) is effective. While it is certainly true that many aspects of this system can be dramatically improved, the basic concept is sound.

2. Interface is Adequate to the Task

The interface described in Section III.C proved adequate to the task of terrain navigation training. Although as noted, several users expected the controls to correspond more closely to a helicopter, all adapted quickly and showed improved navigation in the VE. From this, it is reasonable to assume that the interface is adequate. If the interface had required excessive cognitive load, it is unlikely that students would have been able to demonstrate improved performance in the 45-minute period. In all likelihood, if the interface had been too difficult, students would have spent the majority of this 45-minute

period learning how to control the viewpoint and access feedback. The number and frequency of times students accessed the feedback mechanisms is at least a rudimentary indication that access to the feedback is sufficient. Although the interface surprises some users, they are able to quickly adapt. A motion interface modeled after fixed wing aircraft controls supports the task of terrain navigation training reasonably well.

3. Feedback is Adequate

Section II.A outlined the difficulties associated with devising and implementing feedback mechanisms for training systems. Based on the summary presented in Wickens (1992), it is clear that at least to some degree, the current implementation provides appropriate feedback. If, as in Lintern's study of student aviators learning to land aircraft (Lintern 1990), feedback drew excessive attention from the task, performance during training sessions would have suffered. Likewise, if there had been excessive delay between training and feedback, or if the feedback created dependencies, performance in the aircraft would not have improved. Based on the results presented in Chapter VI, this was clearly not the case. Students were able to improve their navigation performance during the training sessions, and showed improved performance in the aircraft when compared to those who received only conventional training. Although the design and implementation of feedback in training systems should be an iterative process, this implementation provides an adequate initial benchmark for the feedback required in a helicopter terrain navigation training system.

4. Real-world Validation is Possible

It is feasible to use an unaltered pre-existing task as the measure of effectiveness of a proposed training system. While implementing a new system is a difficult process, measuring the effect of the new system without seriously impacting the training program is considerably more difficult. This work demonstrates that these difficulties can be overcome. Despite the serious compromises made for data collection, (for example: experimenters not having the opportunity to observe student performance *during* training flights), the immediacy of both IP's and FRP's responses bolsters the empirical data.

Although it provided the necessary information, data collection for this thesis was extremely limited. Ideally, before and after testing would have been used to measure improvement. An experiment group could receive VE training between their first and second terrain navigation flights. By comparing their performance to a control group that did not receive VE training, any performance difference could be attributed directly to the VE experience. Unfortunately, this was not possible with the current implementation. Although, from the statistician's viewpoint, this experiment would not have sufficient power from which to draw conclusions, the reactions of users lend credibility to the data. The specific features that make one system more effective than another, however, may not be as easy to ascertain using the coarse measures this experiment relied on.

B. FUTURE WORK

While the initial results of this research are promising, this work raises more questions than it begins to answer. Research into these topic areas could improve Navy and Marine Corps helicopter training and provide a valuable source of research data for the Naval Postgraduate School.

1. Field a Long Term System as a Permanent Squadron Asset

While this work proves that it is possible to exploit a closed-loop, producer-consumer cycle to design and implement a component of a real-world training program, this process is labor intensive for experimenters, and could be less obtrusive for squadron personnel. A more productive setup would provide unlimited access for training squadron personnel and unobtrusive data collection for NPS personnel. If the system could be set up as a squadron asset, the squadron would have ample opportunity to explore various modes of operation. Simple, automated data collection routines could provide research personnel a wealth of useful information, eliminating the problems of data collection discussed in Section VII.A.4. This information, compared to student performance, could be used to study a variety of human-computer interface issues. These issues include: Does performance on the trainer correspond to performance in the aircraft? Is the system more effective for mission rehearsal or skill training? Does field of view impact situational awareness?, and Are VEs effective tools for increasing spatial

knowledge of an environment? Fielding a system that remains at HS-10 for unlimited use by students and instructors would greatly enhance squadron training and provide a uniquely rich source of research data for NPS.

2. Explore Impact of FOV (Single Screen and HMD)

How dramatic an effect does field of view have on training and rehearsal systems? Would this same training system be as effective if it used a single monitor configuration? The implications of these questions are profound and should be pursued. As HMD technology improves, it may be feasible to incorporate a digital version of the conventional paper map. If an effective interface to this paper map could be developed, would a more immersive VE experience lead to improved performance in the aircraft? If so, can the issues of simulator sickness be overcome? If these issues could be resolved, incorporating a HMD would substantially reduce the footprint of the system and increase it's utility as a deployable system.

3. Evaluate Mission Rehearsal Mode

Of the suggested uses outlined in Section III.E, which would be the most effective and productive? What are the differences between a terrain navigation training system and a helicopter mission rehearsal system? Is it merely the terrain model and the name? Perhaps of all the topics discussed, this is the most critical. This system has been presented to over two dozen groups. Individuals briefed include The Vice Chief of Naval Operations (VCNO), The Director of Space Information Warfare, Command and Control (N6), and the Director of Naval Training (N7). At every brief, without prompting, the issue of mission rehearsal has been raised. Every group has noted the similarity of this system to mission rehearsal systems. Of particular note, crewmembers involved with the mission that attempted the recovery of the French transport plane in Bosnia were interested in this system as a more appropriate *helicopter* mission rehearsal system as compared to TOPSCENE (C. Schreiber, personal communication, April 15, 1998; S. Linnell, personal communication, May 30, 1998). These crews had access to TOPSCENE, but, primarily because of the narrow field of view, found it left them short while navigating the mountainous terrain of Bosnia. While TOPSCENE is apparently

effective as a fixed wing mission rehearsal system, in practice does it fit the unique requirements of the helicopter community? Indications are that it does not.

4. Investigate Alternative Training Methods

Could the same training effect be achieved with even more basic training systems? Our understanding of terrain association training is extremely limited. Perhaps by extending our understanding of this process, we could propose and implement lower-cost, improved training systems. Computers can create nearly infinite alternative representations of both contour maps and terrain models. What combinations of representations and interfaces would result in the most cost-effective training? Could a basic PC support a simple world-in-hand metaphor with a variety of terrain models and achieve similar performance gain? Can this same training be achieved by incorporating a terrain association course in the existing Survival Evasion Resistance Escape (SERE) training? The answers to these questions could save training time and funds. Pursuing answers to the questions raised by this research is in the best interest of the Navy and Marine Corps team.

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APPENDIX A. SUPPLEMENTAL GRADE CARD

AC-17 SUPPLEMENTAL GRADE CARD

Overall Terrain Navigation Performance

BA AA

Estimated Number of Errors
(Misidentified features, check points, wrong turns)

Error Recovery

BA - AA

Terrain Feature Identification

BA AA

Value of Terf Nav Training Time/FRP Progress

BA AA

Comments:

TERF EVALUATION CRITERIA

Overall Terrain Navigation Performance:

BA: Relied heavily or entirely on DR techniques.
Spent a significant amount of time lost
Had significant difficulty maintaining orientation

AA: Correctly identified terrain features necessary to maintain track.
Arrived at checkpoints within ±30 secs.

Number of Errors

Wrong turns. Misidentified critical features. Required correction by IP

Error Recovery

BA: Required significant time and guidance to regain orientation.

AA: Regained orientation with minimal cues.

Terrain Feature Identification

BA: Required significant time/help to identify critical features.

AA: Consistently relied on terrain features to maintain orientation.

Value of Time/Student progress

BA: Spent significant amount of time on fundamental skills
FRP overwhelmed with navigation, little time for other tasks
Marginally improved navigation skills

AA: Showed significant improvement in navigation skills

Comments:

Any additional comments relating to student's performance or terrain navigation training in general.

APPENDIX B. GRAPHIC DEPICTION OF TRAINING SESSIONS

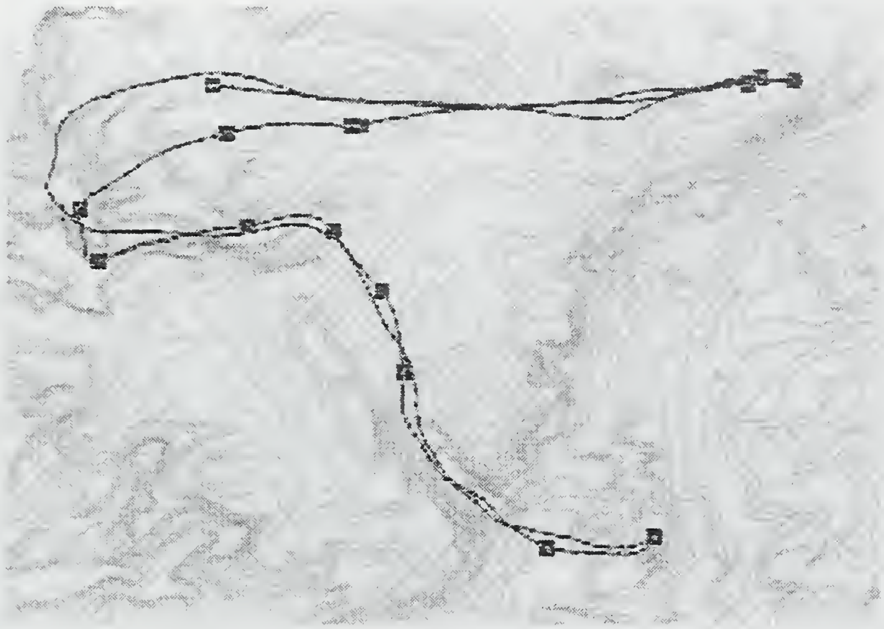

Figure 30. Subject one.

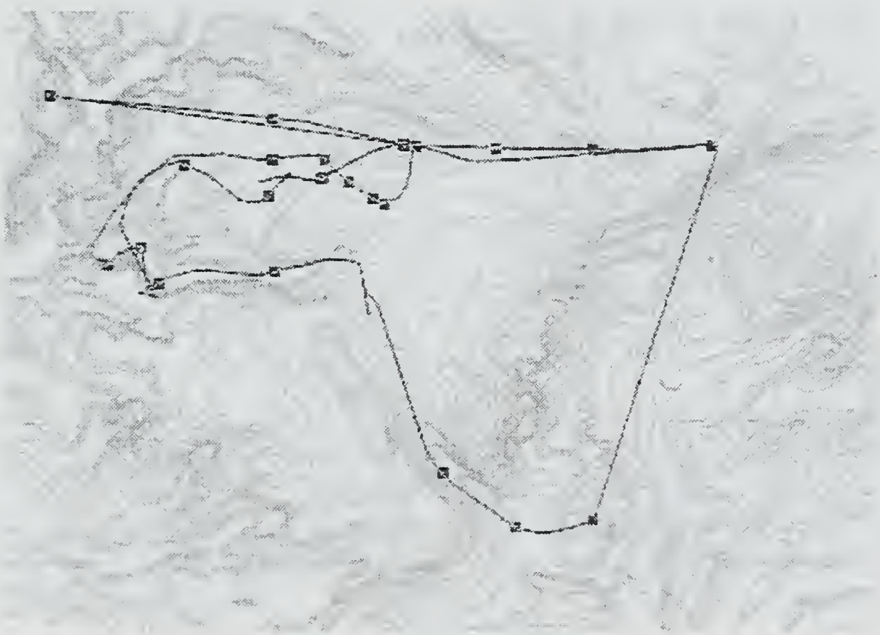

Figure 31. Subject two.

APPENDIX B. GRAPHIC DEPICTION OF TRAINING SESSIONS

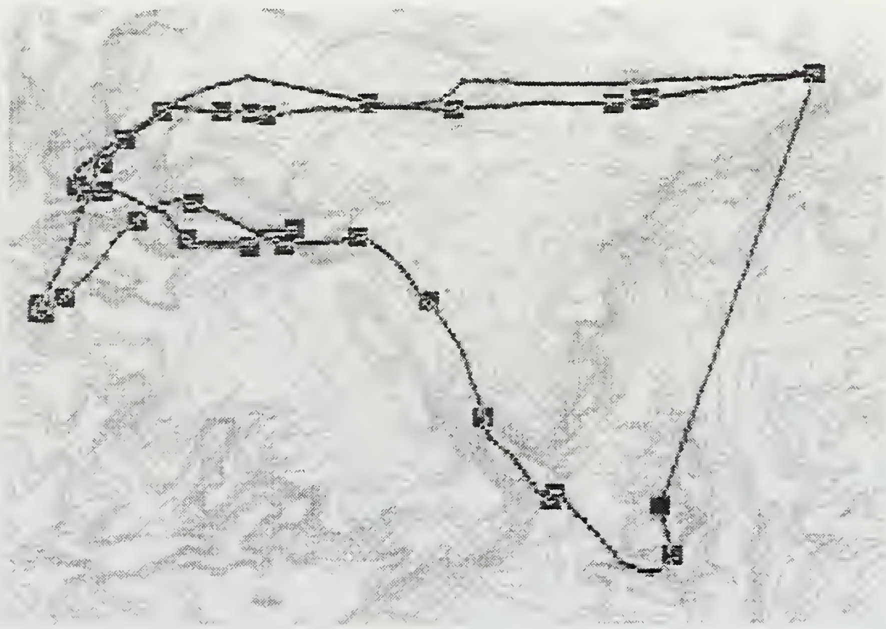

Figure 32. Subject three.

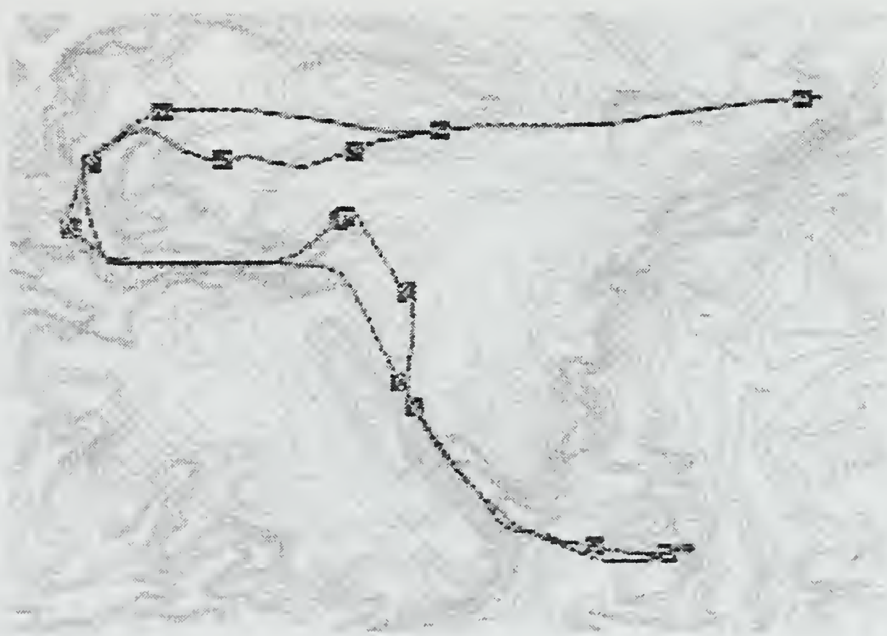

Figure 33. Subject four.

APPENDIX B. GRAPHIC DEPICTION OF TRAINING SESSIONS

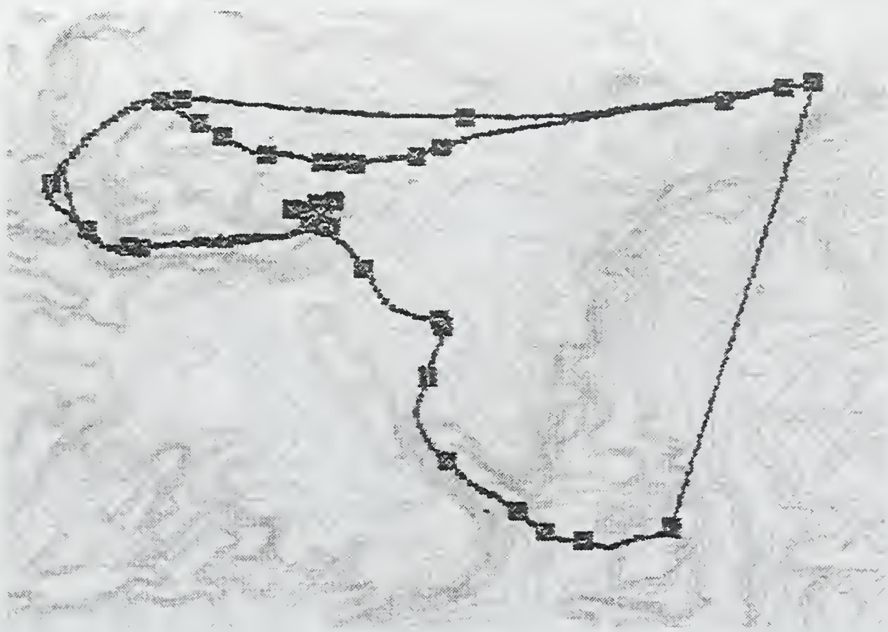

Figure 34. Subject five.

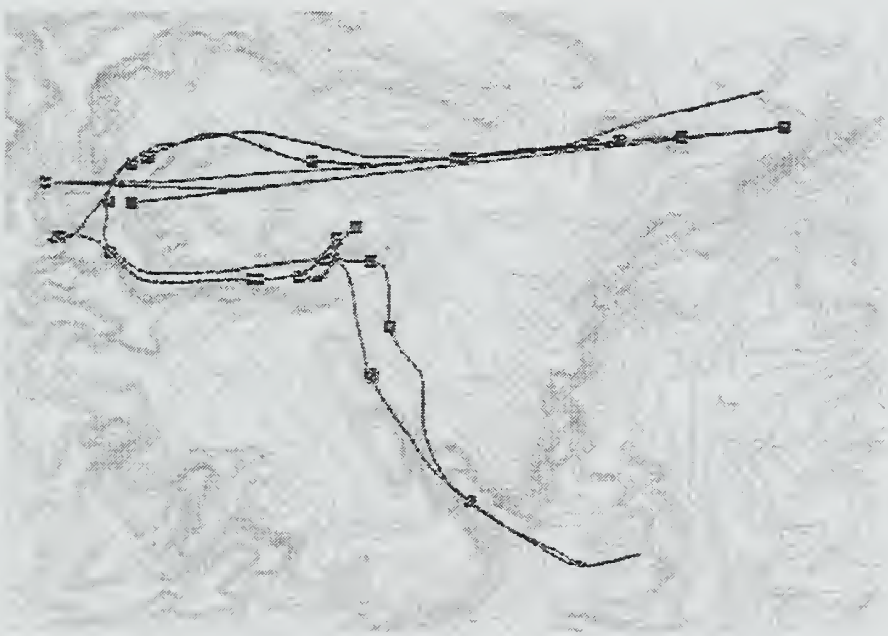

Figure 35. Subject six.

APPENDIX B. GRAPHIC DEPICTION OF TRAINING SESSIONS

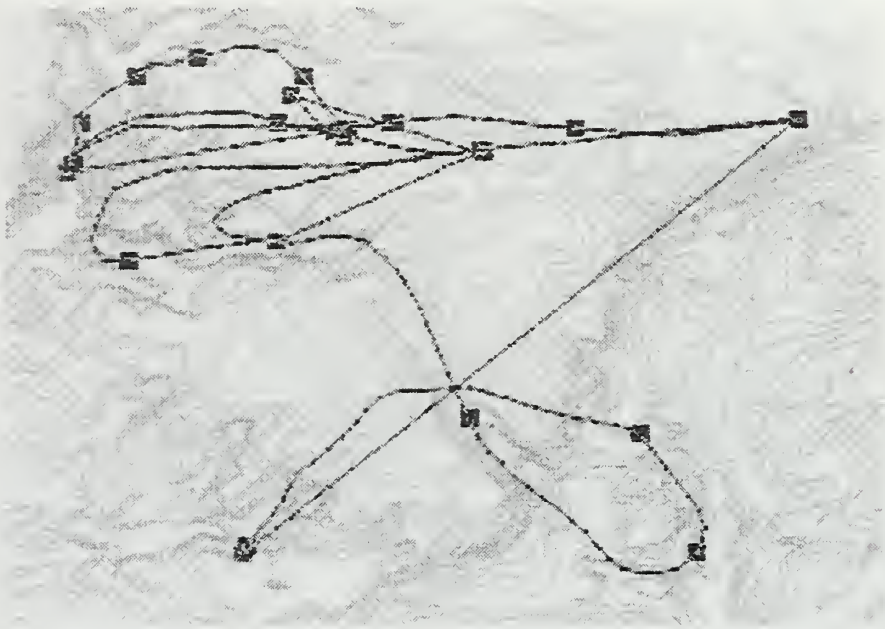

Figure 36. Subject seven.

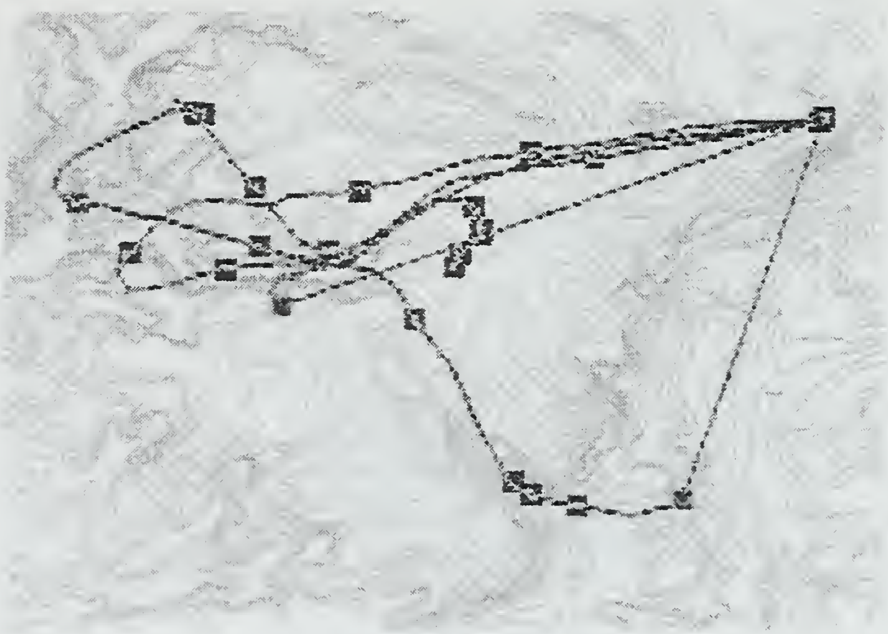

Figure 37. Subject eight.

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